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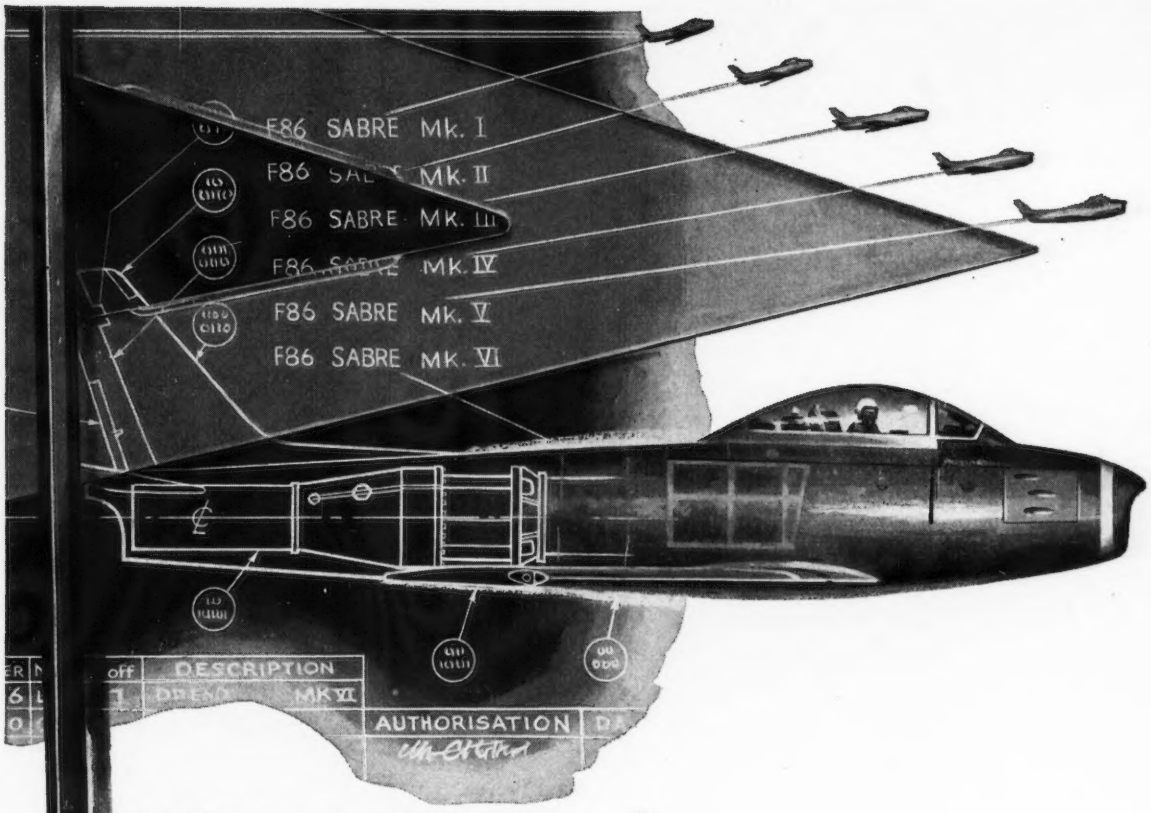

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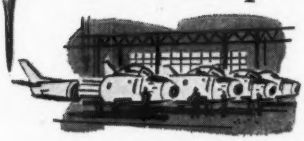

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EDITORIAL

INTERNATIONAL CONFERENCE

THE forthcoming meeting of the C.A.I. and the I.A.S., the second of its kind, points up two matters of some significance. In the first place, it is clear that the C.A.I. has now progressed well beyond its formative stages and is firmly established in the second year of its operations. For this we offer our congratulations and extend our hopes for many more years of active and useful life. The second, no less significant, deserves perhaps a little more discussion at this time. The fact that there now exists a continuing program for collaboration and joint activity among the three leading aeronautical societies of the English speaking world is indeed a matter of moment.

Following the close of World War II a number of people on both sides of the Atlantic, members of the R.Ae.S. and the I.A.S. respectively, foresaw the gains that might be made from international collaboration in the aeronautical sciences. The history of that effort is now well known. The success of the recent Fifth International Conference held in Los Angeles testifies to the soundness of the original idea. Plans which are now afoot for the 1957 Conference give indication of a continuing acceptance of the idea for the foreseeable future.

As N. E. Rowe, President of the R.Ae.S., said at the opening of the Fifth International Conference,

> "I think these conferences are very deeply significant of some of the most important facets of our work, not only as engineers and scientists in our own countries but in relation to what goes on in wider fields.
>
> "Firstly, perhaps, these conferences are a great tribute to the wonderful spirit of association which has always distinguished the meetings between our two Associations —yours a young and vigorous and virile aeronautical body and ours with its roots rather deep in history but, I hope, still retaining some of the vigor that distinguishes your great industry.
>
> "This spirit of association is one of the important things of life, and it, perhaps, is also reflected in the way in which our two countries have steadily moved closer together in this great field of aeronautics and moved more closely together because success in aeronautics is the key to peace. If peace is preserved, then aeronautics can go forward and garner the fruits by way of our transport and other means in which it can revolutionize the surface of things more rapidly than any other power we have today.
>
> "That is the significance of these conferences. It represents so much for us. These conferences have been great meeting grounds for people with common interests. When aeronautical people get together, there is always a tremendous stimulus of thought. They are dealing with pioneering matters, and they get together and find friendships. It is in the renewing of friendships and in the creating of new friendships that these conferences play one of their greatest parts."

Canada has participated in the joint R.Ae.S.-I.A.S. Conference in many ways. A number of individuals have been in attendance and Canadian papers have appeared on the programs. Thus Canada has already made appreciable contribution to the international effort. With the formation of the C.A.I. the question naturally arose as to future joint collaboration on a Society basis. Discussions have already been undertaken in the Councils of all these groups to lay the ground work for the future. So far, no specific program has been agreed upon, but it is to be confidently anticipated that full scale collaboration will be attained in the near future. Meanwhile by taking every opportunity for joint action on a bilateral basis, a solid foundation is being built on which ultimate three-way cooperative effort can be based. There has always been extensive Canadian participation in I.A.S. meetings and, on an increasing scale, there has been active collaboration at all levels between the C.A.I. and the I.A.S. Last year's meeting in Montreal and the upcoming Conference in Ottawa illustrate the point.

In the final analysis, meetings are the principal stock-in-trade of the professional societies. They are successful only in so far as they provoke discussion and interchange of ideas. Nothing could be more important than free and frequent exchange among British, Canadian and American engineers.

We are all looking forward to a continuation of this form of activity and also to more and more active participation by C.A.I. members in regular I.A.S. sessions including our Annual Meeting in New York, and some of the more specialized sessions such as the National Turbine-Powered Air Transportation Meeting. The precedent has already been established. It is now our joint obligation to explore and exploit to the full every useful aeronautical idea on an international basis.

CAPT. S. PAUL JOHNSTON,
Director,
Institute of the Aeronautical Sciences.

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It is my great pleasure to announce that His Royal Highness the Duke of Edinburgh has graciously honoured the Canadian Aeronautical Institute by becoming its Patron.

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His Royal Highness' interest in aviation is well known. He has qualified for his "wings" and is a practising pilot. Moreover his use of both fixed and rotary wing aircraft in the performance of his duties exhibits an imaginative approach to flying as the modern means of transportation.

During his tour of Canada in August, 1954, he displayed a knowledgeable interest in aeronautical matters and later, in the 1954 British Commonwealth and Empire Lecture which he delivered to the Royal Aeronautical Society, he commented on the ability of Canadian scientists, engineers and technicians. He has now honoured their society with his patronage.

President

HIGH TAILPIPE MACH NUMBERS IN REHEATED TURBOJET ENGINES†

by E. Philip Cockshutt*

National Aeronautical Establishment, Ottawa

SUMMARY

Analysis indicates that if a low Mach number is used in a reheat tailpipe, the tailpipe diameter is likely to exceed the diameter of the engine proper. It is shown that there is always a thrust loss if the tailpipe Mach number is increased, but the percentage loss is small under static conditions, and extremely small under high speed flight conditions. A criterion is formulated for the maximization of powerplant thrust per unit frontal area using a high-boost reheat system.

INTRODUCTION

In order to augment the thrust of a turbojet engine, it is becoming increasingly common to reheat the working fluid by afterburning or tailpipe combustion before it is expanded through the propelling nozzle. The essential components of such a system are illustrated in Figure 1, where the system of subscripts used herein is established; the working fluid passes from the turbine of a conventional turbojet engine through a diffuser (4-5), across a flame holder (5-6), through the cylindrical tailpipe which acts as the reheat combustion chamber (6-7), and through the propelling nozzle (7-8).

It is the purpose of this paper to assess the importance of the gas Mach number at the diffuser outlet (station 5), in so far as it affects the size and thrust of the powerplant. These two aspects are examined in detail in the following two sections; a final section examines qualitatively the effects of tailpipe Mach number changes on the combustion process.

SYMBOLS

A	area (ft^2)
A_0	outside area (ft^2)
C_D	flame holder drag coefficient
C_{pc}	specific heat at constant pressure–compressor [Btu/(lb_m °C)]
C_{pt}	specific heat at constant pressure–turbine [Btu/(lb_m °C)]
d	differential increment
D	baffle dimension (area : perimeter) (ft)
F	thrust (lb)
F_g	gross thrust (lb)
F_n	net thrust (lb)
G	mass velocity [lb_m/(sec ft^2)]
g	dimensional constant (=32.2 lb_m ft/lb_w sec^2)
L	reheat pipe length (ft)
M	Mach number

†Received 25th May, 1955.

*Engine Laboratory.

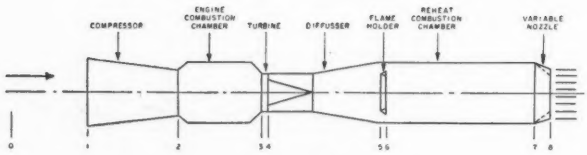

Figure 1

Reheated turbojet engine

P_S	static pressure (lb/ft^2)
P_T	total pressure (lb/ft^2)
R	air gas constant (=96.0 $lb_w ft/lb_m$ °K)
T_S	static temperature (°K)
T_T	total temperature (°K)
V	velocity (ft/sec)
W	mass flow (lb_m/sec)
α	ratio of blocked area to duct area
γ	ratio of specific heats–tailpipe
γ_c	ratio of specific heats–compressor
γ_t	ratio of specific heats–turbine
$\triangle T_c$	compressor total temperature rise (°C)
$\triangle T_t$	turbine total temperature drop (°C)
ε	area ratio (A_0/A)
η_b	reheat combustion efficiency
η_c	isentropic compressor efficiency
η_d	isentropic diffuser efficiency
η_n	isentropic nozzle efficiency
η_T	isentropic turbine efficiency
τ	fuel ignition delay (sec).

Subscripts

0 free stream conditions
1 compressor inlet
2 combustion chamber inlet
3 turbine inlet
4 diffuser inlet
5 flame holder inlet
6 reheat combustion chamber inlet
7 propelling nozzle inlet
8 nozzle exit

THE EFFECTS OF TAILPIPE MACH NUMBER ON POWERPLANT SIZE

Significance of mass velocities

It may be shown that the thrust developed by a turbojet engine is directly proportional to the mass flow of air through it, provided the thermodynamic cycle is unchanged. The drag of such an engine, on the other hand, is generally proportional to its frontal area. Hence the

engine mass velocity, defined as the ratio of the air mass flow to the engine frontal area, may be regarded as a figure of merit indicating the ratio of the developed thrust to the accompanying drag.

It is also convenient to consider the tailpipe mass velocity, which is defined as the air mass flow through the engine divided by the tailpipe cross-sectional area. It will be seen that if the tailpipe mass velocity is less than the engine mass velocity, then the tailpipe area will exceed that of the engine proper. This quantity thus provides a convenient criterion of tailpipe size.

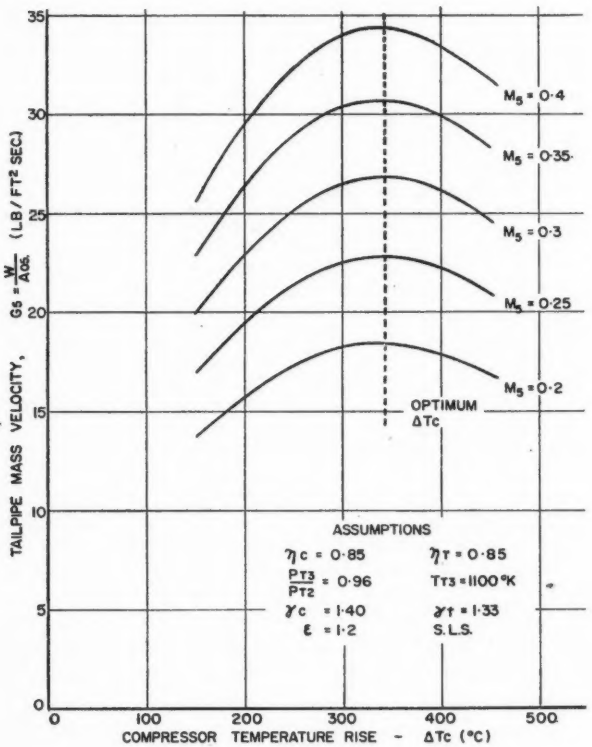

Figure 2
Tailpipe mass velocities

Comparison of mass velocities

The state of a fluid in motion is defined by any three independent properties; those frequently convenient in gas turbine analysis are the total pressure, P_T, the total temperature, T_T, and the Mach number, M. The mass velocity in the tailpipe may be expressed in terms of these three parameters as follows:

$$G_5 = \frac{W\sqrt{\theta}}{A_{05}} = P_{T5} M_5 \left[1 + (\gamma - 1) M_5^2/2\right]^{-\frac{1+\gamma}{2(\gamma-1)}} \sqrt{\frac{\gamma g}{R}} \Big/ \left(\varepsilon \sqrt{T_{T5}}\right) \tag{1}$$

The dimensionless ratio ε is the ratio of the outside area to the inside area of the tailpipe, and hence accounts for an insulating annulus around the tailpipe. The tailpipe total pressure and total temperature may be expressed in terms of the more fundamental engine parameters, temporarily neglecting losses in the diffuser, as follows:

$$P_{T5} = P_{T1}\left(1 + \eta_c \Delta T_c / T_{T1}\right)^{\frac{\gamma_c}{\gamma_c - 1}} \frac{P_{T3}}{P_{T2}} \left[1 - \Delta T_t / (\eta_t T_{T3})\right]^{\frac{\gamma_t}{\gamma_t - 1}} \tag{2}$$

$$T_{T5} = T_{T3} - \Delta T_t \tag{3}$$

where $\triangle T_c$ and $\triangle T_t$ fulfil the relation

$$C_{pc} \Delta T_c = C_{pt} \Delta T_t \tag{4}$$

Figure 2 is a plot of the tailpipe mass velocity, G_5, versus the compressor temperature rise, $\triangle T_c$, for various values of the tailpipe Mach number, M_5. Representative values for the other engine parameters were selected and are indicated on the figure; sea level static operation is assumed. It is of considerable interest to note the compressor temperature rise which gives a maximum mass velocity in the tailpipe; for the selected parameters this amounts to a temperature rise of 343°C or a sea level static pressure ratio of 12.0.

These tailpipe mass velocities must be considered in conjunction with engine mass velocities. It is seen that a typical engine with a mass velocity of 20 lb_m/ft^2sec requires a Mach number of the order of 0.25 to keep the tailpipe smaller than the engine. A more ambitious engine design with a mass velocity of 25 lb_m/ft^2sec would require a tailpipe Mach number of about 0.30, and a still more highly developed engine with a mass velocity of 30 lb_m/ft^2sec would require a tailpipe Mach number in excess of 0.35 to keep the tailpipe smaller than the engine. Thus, if reheat is to be applied to such engines, there will be a strong demand for operation with high tailpipe Mach numbers.

THE EFFECTS OF TAILPIPE MACH NUMBER ON POWERPLANT THRUST

This section outlines the thrust changes which accompany changes in the tailpipe Mach number; it is assumed herein that the nozzle area is so adjusted that the state of the fluid at exit from the turbine, as specified by P_{T4}, T_{T4}, and M_4, is not changed. Assuming a choked convergent propelling nozzle and a freely adjustable nozzle area, the gross thrust developed by an engine may be shown to be

$$F_g = \left[(\gamma + 1) - \left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}} P_{S0}/P_{T8}\right] W \left\{2RT_{T8}/[\gamma g(\gamma+1)]\right\}^{\frac{1}{2}} \tag{5}$$

The final pressure ratio, P_{T8}/P_{S0}, may be written as the product of the turbine outlet pressure ratio, P_{T4}/P_{S0}, and the tailpipe pressure ratio P_{T8}/P_{T4}; thus

$$P_{T8}/P_{S0} = (P_{T4}/P_{S0})(P_{T8}/P_{T4}) \tag{6}$$

Since, by hypothesis, P_{T4} and P_{S0} are unchanged, the tailpipe Mach number will influence the gross thrust only in so far as it affects the tailpipe pressure ratio, P_{T8}/P_{T4}.

In order to determine the total pressure at exit from the tailpipe, station 8, it is necessary to trace the fluid state through the tailpipe from the turbine outlet. The following paragraphs discuss the state changes across the four components involved — the diffuser, the flame holder, the combustion chamber, and the propelling nozzle.

Component pressure losses

It is convenient to describe the performance of the diffuser with an isentropic efficiency which is defined in the same way as that of a compressor, i.e., as the ratio of the static temperature rise accompanying an isentropic diffusion to the actual static temperature rise, when both processes are carried to the same final static pressure. The total pressure at the diffuser outlet may be written in terms of this isentropic efficiency, η_d, as

$$P_{T5}/P_{T4}=\left[\eta_d+\left(1-\eta_d\right)\left(1+\frac{\gamma-1}{2}M_5^2\right)\Big/\left(1+\frac{\gamma-1}{2}M_4^2\right)\right]^{\frac{\gamma-1}{\gamma}} \tag{7}$$

It will be noted that both the initial and final Mach numbers must be specified as well as the isentropic efficiency before the total pressure ratio is uniquely determined.

Because of the uncertainties involved, it is considered sufficiently accurate to analyse the flow across the flame holder as a Fanno Line process (i.e., as a one-dimensional, constant-area, adiabatic flow subject to friction). For small Mach number changes the following relations may be demonstrated:

$$P_{T6}/P_{T5}=1-\gamma M_5^2 C_D\alpha/2 \tag{8}$$

$$M_6/M_5=\sqrt{\left[1+\gamma M_5^2\left(1+\frac{\gamma-1}{2}M_5^2\right)C_D\alpha\Big/\left(1-M_5^2\right)\right]} \tag{9}$$

In these expressions C_D is the flame holder drag coefficient, based on the flame holder frontal area, and α is the ratio of the flame holder area to the duct area.

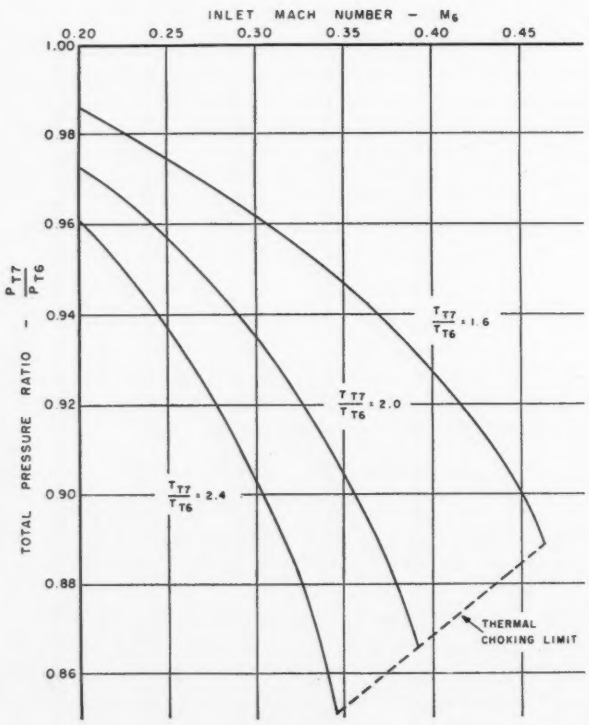

Figure 3
Calculated combustion chamber performance
($\gamma = 1.3$)

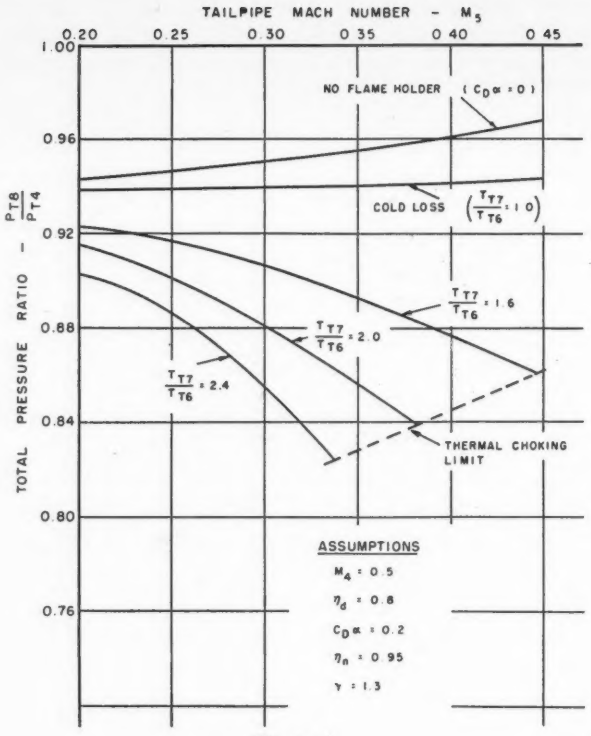

Figure 4
Tailpipe pressure losses (typical parameters)

It will be seen that the performance of the flame holder is uniquely determined by the product $C_D\alpha$.

The combustion process is conveniently analysed as a Rayleigh Line process (i.e., as a one-dimensional, constant-area, frictionless flow subject to a total temperature change). For such a process the following relations for the total pressure and total temperature may be demonstrated:

$$\frac{P_{T7}}{P_{T6}}=\frac{1+\gamma M_6^2}{1+\gamma M_7^2}\left[\frac{1+\frac{\gamma-1}{2}M_7^2}{1+\frac{\gamma-1}{2}M_6^2}\right]^{\frac{\gamma}{\gamma-1}} \tag{10}$$

$$\frac{T_{T7}}{T_{T6}}=\frac{M_7^2}{M_6^2}\left[\frac{1+\gamma M_6^2}{1+\gamma M_7^2}\right]^2\frac{1+\frac{\gamma-1}{2}M_7^2}{1+\frac{\gamma-1}{2}M_6^2} \tag{11}$$

These functions are presented in Figure 3, where the total pressure ratio P_{T7}/P_{T6} is shown as a function of the inlet Mach number M_6, and the total temperature ratio, T_{T7}/T_{T6}. A feature of particular importance in the combustion process is the phenomenon of thermal choking; the greater the total temperature ratio (i.e., the greater the reheat fuel flow) the lower must be the inlet Mach number to avoid choking. The rapid increase in the total pressure loss with the inlet Mach number is also striking, and has been an important reason for avoiding high Mach numbers in the tailpipe.

The performance of the nozzle, like that of the diffuser, is conveniently described by an isentropic efficiency; this efficiency is defined as the ratio of the actual static temperature drop to that which would be obtained in isentropic expansion to the same static pres-

sure. If it is assumed that a simple convergent nozzle is used and that it runs choked, the following relation may be demonstrated for the total pressure ratio, P_{T8}/P_{T7}, as a function of the nozzle efficiency, η_n.

$$P_{T8}/P_{T7} = \left\{ \left[1-(\gamma+1)(1-\eta_n)/[2+(\gamma-1)M_7^2] \right] / \eta_n \right\}^{\frac{\gamma}{\gamma-1}} \quad (12)$$

Overall pressure losses

A review of the foregoing component analysis indicates that evaluation of the tailpipe pressure ratio, P_{T8}/P_{T4}, requires that M_4, η_d, M_5, $C_D\alpha$, T_{T7}/T_{T6} and η_n all be specified. Figure 4 shows the tailpipe pressure ratio as a function of the tailpipe Mach number, M_5, for values of M_4, η_d, $C_D\alpha$ and η_n which are believed typical. Curves are shown for three degrees of reheat (T_{T7}/T_{T6} = 1.6, 2.0 and 2.4), for the "cold" condition (T_{T7}/T_{T6} = 1.0) and for just the nozzle-diffuser combination (flame-holder removed). It is of considerable interest to note that the "cold" loss is virtually independent of the tailpipe Mach number, M_5; this results from the increasing flame holder losses being counteracted by the decreasing diffuser and nozzle losses as M_5 is increased. This observation implies the controlling importance of the "fundamental" total pressure loss in the combustion chamber. With M_5 equal to 0.3, and T_{T7}/T_{T6} equal to 2.0 exactly half the total pressure loss takes place in the combustion chamber.

It is also immediately obvious that thermal choking provides a very real limit to the maximum useful value

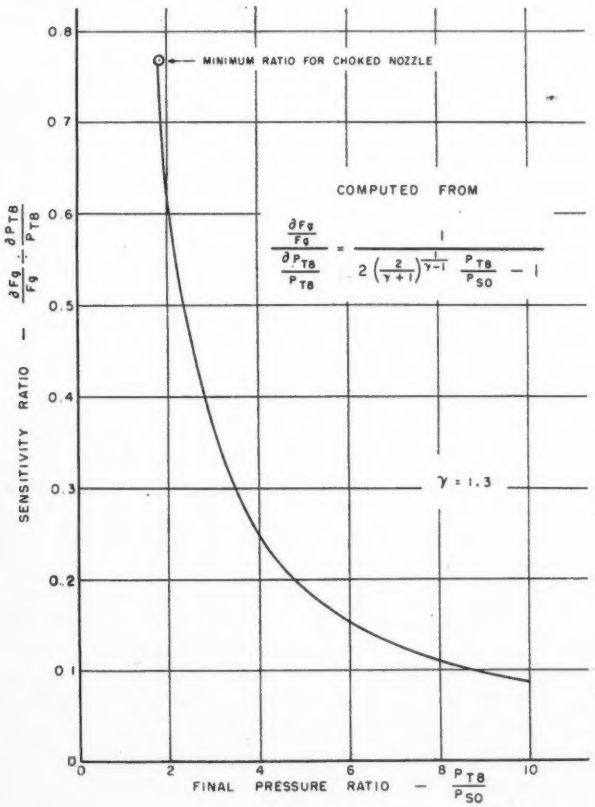

Figure 5
Sensitivity of gross thrust to total pressure

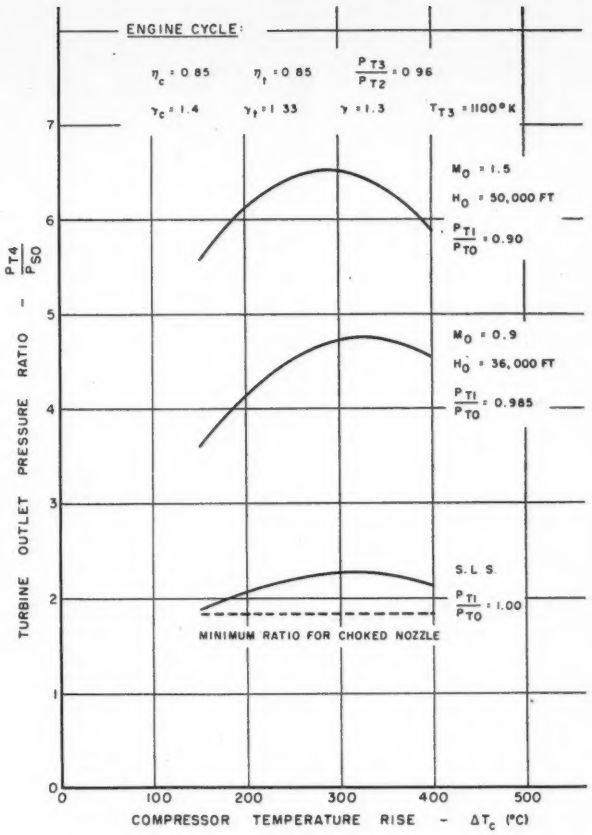

Figure 6
Turbine outlet pressure ratio

of M_5; with a "full-boost" system ($T_{T7}/T_{T6}>2$), M_5 must be kept below about 0.35.

Powerplant thrust

In considering the effects of the total pressure loss on the engine thrust, it is instructive to take logarithmic differentials in the gross thrust equation (5); this operation yields

$$(dF_g/F_g)/(dP_{T8}/P_{T8}) = \left\{ 2\left[2/(\gamma+1) \right]^{\frac{1}{\gamma-1}} P_{T8}/P_{S0} - 1 \right\}^{-1} \quad (13)$$

This relation is plotted in Figure 5 with the final pressure ratio, P_{T8}/P_{S0}, as the abscissa; the ordinate represents the sensitivity of the gross thrust to the final total pressure (i.e., the percentage change in gross thrust which accompanies a one percent change in the final total pressure). The strong effect of the final pressure ratio on this sensitivity is most striking; as the final pressure ratio increases from 2.0 to 6.0, the thrust sensitivity is quartered.

Figure 6 is a plot of the turbine outlet pressure ratio, P_{T4}/P_{S0}, which has been computed from equation (2) presented above; the ram ratios have been reduced from the isentropic values by the factors indicated. For compressor temperature rises greater than 200°C, the turbine outlet pressure ratio is the order of 2.0 for sea level static, 4.0 for an aircraft Mach number of 0.9, and 6.0

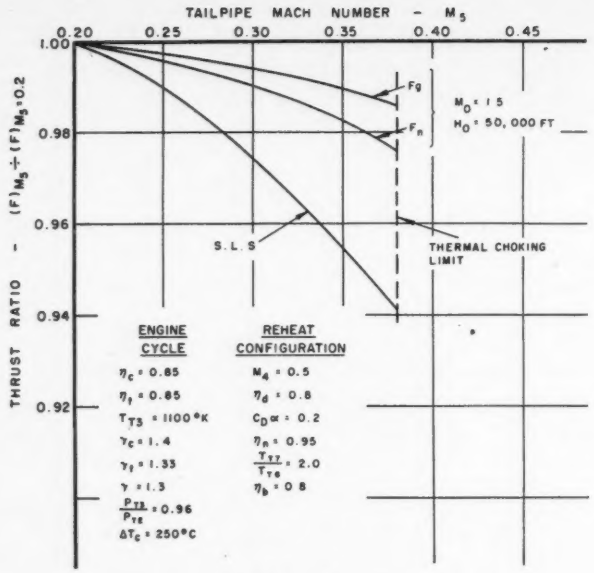

Figure 7
Response of engine thrust to tailpipe Mach number

for an aircraft Mach number of 1.5. Hence at high flight Mach numbers the gross thrust will be very insensitive to total pressure losses.

Figure 7 represents a combination of the foregoing plot of the turbine outlet pressure ratio, P_{T4}/P_{S0}, the previous study of the tailpipe total pressure loss, P_{T8}/P_{T4}, and the thrust equation. Since the airframe designer is interested in the net engine thrust rather than the gross thrust, both gross and net thrusts are

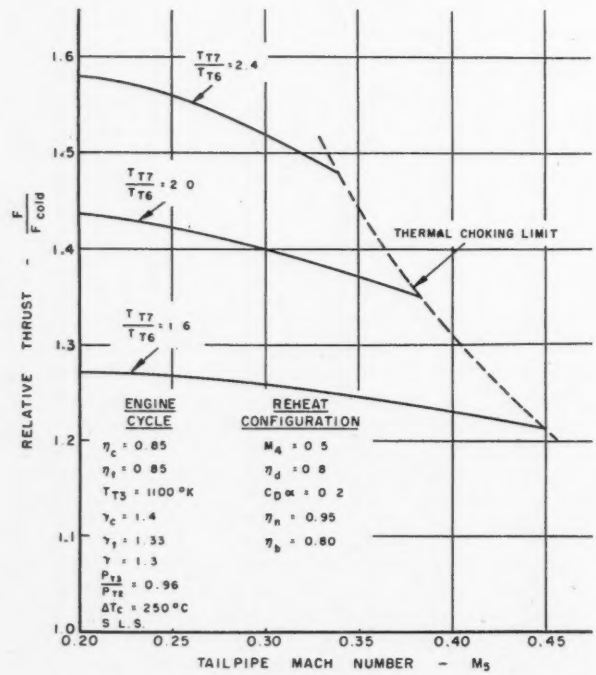

Figure 8
Sea level static thrust

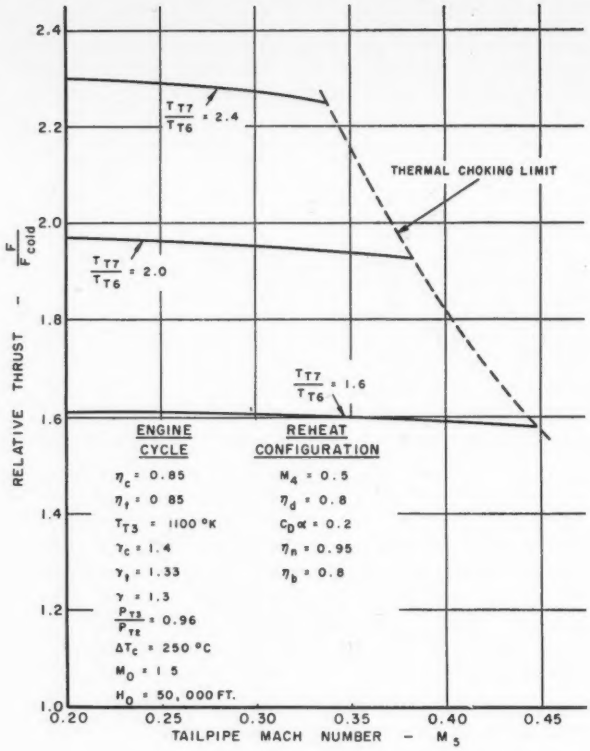

Figure 9
Net thrust in supersonic flight

shown for the selected flight condition ($M_0 = 1.5$, $H_0 = 50{,}000$ ft). The ordinate of Figure 7 is the engine thrust with any selected tailpipe Mach number, M_5, divided by the thrust with $M_5 = 0.2$; the reheat temperature ratio is 2.0, and the other independent parameters selected are indicated.

It is obvious that the engine thrust decreases continuously as the tailpipe Mach number increases up to the thermal choking limit; as has been suggested previously this is primarily due to the increasing fundamental total pressure loss in the combustion chamber.

It is also obvious that the thrust loss is much less serious at high aircraft Mach numbers; statically there is a 6% thrust loss accompanying a tailpipe Mach number increase from 0.2 to 0.38, while at a flight Mach number of 1.5 there is a 1.5% gross thrust loss or 2.5% net thrust loss for the same increase in the tailpipe Mach number.

In Figure 8, the sea level static thrust boosts are examined in detail. This figure shows the thrust boost for three reheat temperature ratios as a function of the tailpipe Mach number, M_5; the ordinate is the ratio of the reheated engine thrust to the thrust under the "cold" condition ($T_{T7}/T_{T6} = 1.0$) and a tailpipe Mach number of 0.20. It is evident that thermal choking provides a very real limitation to the thrust boost obtainable once the tailpipe Mach number reaches about 0.35. The calculations were based on equation (5), and allowance was made for the weight of reheat fuel added (assuming a combustion efficiency of 0.80).

Figure 9 illustrates the net thrust boosts for supersonic flight ($M_O = 1.5$ at $H_O = 50{,}000$ ft). It is interesting to note that the net thrust boost for a given temperature ratio is much greater than the sea level static boost; this is of course due to the fact that the ram drag is constant while the gross thrust behaves substantially like the sea level static thrust. The decreased sensitivity of the thrust to the tailpipe Mach number is illustrated by the flatter curves, compared with the static case.

Thrust per unit tailpipe area

The above paragraphs have indicated the change in the thrust available from a given power plant as the tailpipe Mach number is varied. It has been demonstrated previously, however, that the tailpipe diameter may control the power plant size; for this reason there may actually be an improvement from increasing the tailpipe Mach number in spite of the accompanying thrust loss.

Figure 10 is a plot of the thrust per unit tailpipe area for the sea level static case; the ordinate is the ratio of the thrust per unit tailpipe area to the thrust per unit tailpipe area for the "cold" condition ($T_{T_7}/T_{T_6} = 1.0$) and a tailpipe Mach number of 0.20. As one follows a line of constant temperature ratio, there is a large increase in the thrust per unit tailpipe area with increasing tailpipe Mach number. This suggests that to maximize the power plant thrust per unit frontal area, one should increase the tailpipe Mach number until the tailpipe area is just equal to the engine frontal area; there is obviously no gain in increasing the tailpipe Mach number beyond this point.

Figure 11 shows the net thrust per unit tailpipe area for the supersonic flight condition ($M = 1.5$ and $H = 50{,}000$ ft). As would be expected, the increase in the thrust per unit tailpipe area due to reheat is greater than for the sea level static condition; as before there is a pronounced increase in the thrust per unit tailpipe area with increasing tailpipe Mach number.

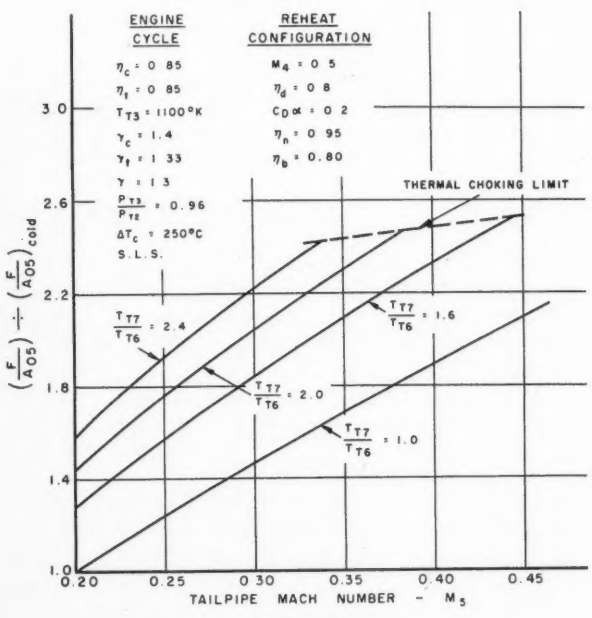

Figure 10
Thrust per unit tailpipe area (sea level static)

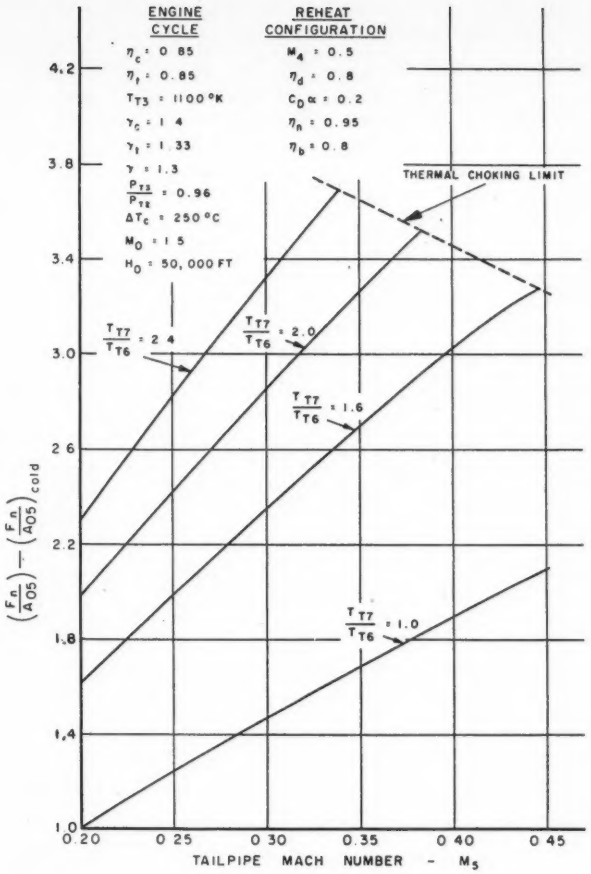

Figure 11
Thrust per unit tailpipe area (supersonic flight)

Of particular significance is the behaviour of the thermal choking limit line on these two plots. For the sea level static case, the thermal choking limit line has a positive slope on the plot of tailpipe Mach number; this would imply that the highest tailpipe Mach number necessary to keep the tailpipe size down to the engine size should be used, even if this requires reducing the temperature ratio to avoid thermal choking. For the supersonic flight condition, however, the thermal choking limit line has a negative slope; this implies that if the tailpipe is larger than the engine, even when running thermally choked, the thrust per unit tailpipe area will increase if one decreases the tailpipe Mach number (increasing the tailpipe size) and simultaneously increases the reheat temperature ratio.

The importance of the power plant thrust per unit frontal area increases with the flight Mach number; for this reason it is the supersonic flight case which is of chief significance. The criterion for maximum thrust per unit frontal area may hence be formulated: the maximum temperature ratio which is chemically achievable should be selected, and the tailpipe Mach number should then be increased until either the tailpipe is decreased to the same size as the engine or else the tailpipe is thermally choked.

THE EFFECTS OF TAILPIPE MACH NUMBER ON REHEAT COMBUSTION

Combustion efficiency

It seems reasonable to expect that the efficiency of a combustion process might be a strong function of the ratio of the residence time of the fuel-air mixture in the combustion chamber to its reaction time. Mullins[2] points out, in a slightly different connection, that at a fixed temperature level the reaction time or ignition delay, τ, is approximately inversely proportional to the pressure. These considerations suggest the possible usefulness of the dimensional reaction parameter, PL/V, which may be considered indicative of the ratio of residence to reaction time.

Figure 12 is a plot of experimental tailpipe combustion efficiency versus this reaction parameter; the significant point is that the data for two different tailpipe Mach numbers (0.21 and 0.26) lie on the same average curve. This suggests that the combustion efficiency is not strongly dependent on the tailpipe Mach number, per se; the implication is that the combustion efficiency would be unchanged on doubling the tailpipe Mach number, provided that the reaction parameter were maintained constant by doubling the tailpipe length. The Mach number range must obviously be greatly extended before this hypothesis may be accepted.

Flame stability

There seems to be general agreement in the literature on flame stabilization [1, 3] that the blow-out velocity of a homogeneous fuel-air mixture increases with increasing baffle size for a series of similar baffles. One set of data supports the theory that the stability limits are a function of the residence time behind the flame holder; this time may be shown to be proportional to D/V, where D is the ratio of the baffle area to the baffle perimeter and V is the gas velocity. The implication of this theory is that if the tailpipe Mach number were doubled it would be necessary to double the baffle dimension D, for example by doubling the width of a Vee-ring flame holder. It remains to be seen whether this relation is applicable to the inhomogeneous mixtures encountered in actual reheat configurations.

CONCLUSIONS

It has been shown that if low Mach number reheat systems are applied to highly developed engines, the tailpipe diameter will exceed the basic engine diameter.

If, on the other hand, the tailpipe Mach number is increased, there will always be a loss of total pressure and hence of engine thrust; it is seen, however, that under conditions of high speed flight the thrust loss is very small. If one chooses to maximize the thrust per unit frontal area, the largest temperature ratio which is chemically achievable should be selected, and then the tailpipe Mach number should be increased until either the tailpipe is as small as the engine or else the tailpipe is thermally choked.

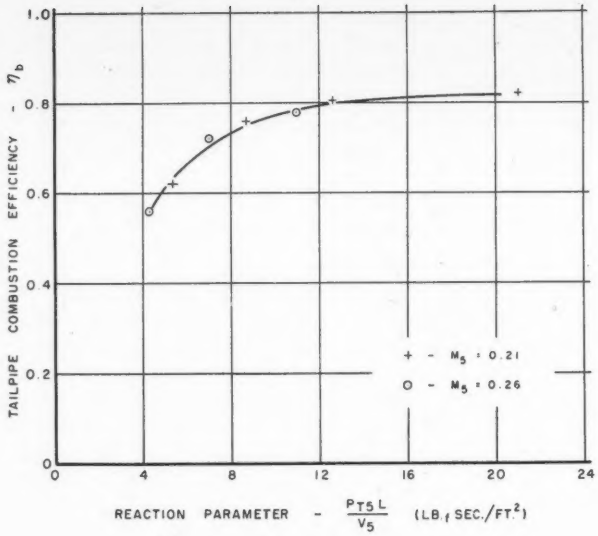

Figure 12
Combustion efficiency study

The problem of combustion in high Mach number tailpipes may prove rather difficult, and should be the subject of intensive study.

ACKNOWLEDGMENT

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INSPECTION: PAST – PRESENT – FUTURE†

by D. T. Jackson*

Department of Transport

In search of material for this paper on Inspection, I naturally assumed that the Technical Library would provide the basic facts. I was quite perturbed, therefore, to find that nothing at all has been written about the early days of inspection. In fact, it is not even known who invented the micrometer, and no one is very sure about the origin of the microscope.

However, there doesn't seem to be any doubt as to when the first inspection in history took place, for in the 31st verse of the first chapter of Genesis we find these words – "And God saw everything he had made, and behold, it was very good".

From that point, it is a comparatively short jump to the time of the ancient Greeks. They didn't know the principle of the arch, and their buildings suffered from it. They did, however, know how to arrive at a true right angle by the use of a cord, or piece of string, divided by knots into three appropriate lengths, and this effective method was used for centuries afterwards.

Remember there were no scientific instrument makers in those days. Euclid is said to have worked out his theorems with a pointed stick in the sands of the seashore, and Archimedes, that other torment of the student, is reliably reported to have made his greatest discovery by overflowing his bathtub. What his landlady said is not recorded.

In olden days and, indeed, right through the middle ages, the only known standards of measurement were those which men carried about with them, i.e., their hands and feet. The "cubit" was the distance from the elbow to the tip of the outstretched forearm, that is 18-20 inches. (Now work out the size of the Great Temple of King Solomon; you will be surprised at the answer.)

The "digit" was the width of a finger – about three-quarters of an inch – and the "palm" was measured across the base of the fingers – about three inches. The "foot" is self-explanatory, but unfortunately people's feet vary from 9 to 19 inches, so presumably it was good business to buy from policemen and sell to dwarfs. Likewise the "span" of a blacksmith was certainly larger than that of a tailor.

As trade grew it became necessary to have more reliable standards of comparison. (Has it every struck you that inspection is nothing but comparison, whether it be pushing on a simple gap-gauge or studying metal under a microscope?)

†Received 7th June 1955.

*Chief Inspector of Aircraft.

Towns, in order to attract business, set up "honest" standards which they enforced impartially, and such towns have left us a legacy of our "Troy" weights (Troyes, France) and our "Winchester" bushel. But soon it became necessary for Parliament to take a hand. By an act of Edward II, it was decreed that the inch was to be the length of three barleycorns placed end to end, the said corns to be taken from the centre of the ear.

The "cloth yard" was a very old standard of measurement – from the point of the nose to the end of the outstretched arm – but as tailors varied in the lengths of their arms, and as cloth merchants seem commonly to have suffered from permanent cramp of the elbow when measuring out, Henry I passed an Act which said that from the point of *his* nose to the tip of *his* outstretched arm was in future to be the standard yard.

It will be noted that cloth was one of the principal articles bought and sold, the other, of course, was land. Here again, the "furlong" (furrow long) must vary according to the length of the strip being furrowed, while everyone knows that the countryman's mile (Roman: "mille" a thousand paces) is to this day different from the townsman's. A decree of the sixteenth century laid down the standard "rod" as the length obtained by placing toe to heel the left feet of sixteen men, taken as they came out of church on Sunday morning – the point being that this would probably be the only time when sixteen men in any village would all be wearing shoes.

At the same time, more Acts were passed dealing with cloth. Wool was often sold by weight, and the number of old Acts which prohibit merchants from wrapping rocks and brick-ends in their bales, shows the popularity of the practice. Where it was sold by length, the merchants hastened to build the great cloth halls of Leeds and Ypres, not as their monument to posterity, but because of the curious effect of rain on woollen cloth!

And so we pass gradually from the old empirical methods of measuring down to the modern state-registered standards. Perhaps the classic example of the latter is the decision taken by the French revolutionary assembly at the end of the eighteenth century. A body of learned men decided that the standard measure of length should be the circumference of the earth divided by one million. Thus was produced the "metre" – a length just too long for the tailor to reach with his outstretched arm, just too long for the farmer to pace with his foot. "At least", you will say, "it was logical". Was

it? They found out afterwards they had got the circumference of the earth all wrong!

The measurements having been settled, we now come to their application. The engineering industry began to take shape after 1750, when old Abraham Darby, of Coalbrookdale, found out how to smelt cast iron with coke, and made himself a cast iron coffin to be buried in, and a cast iron razor to boot. From then on, for 150 years, Britain was the leading engineering country in the world. The steam pump, the steam blast, and the steam hammer were doing wonders long before the steam engine was used to give rotary motion to machinery. And with them there grew up a race of skilled men who knew these monsters, and could make them work. "Millwrights" they were called, and they formed the earliest of our modern trade unions. Steam engines were sent in parts to wherever they were wanted, and erected in situ; no two engines were alike, there was no mass production, and – no inspection (except that a senior man would overlook the work of the apprentice under him). Thread sizes were peculiar to each workshop, and this sad state – partly because of the vested interests involved – went on into the late nineteenth century. Pistons did not fit into cylinders nearer than one-sixteenth. So difficult was it to get a running fit, that the remedy was sought not in the machining but in the packing. (Piston rings were unknown, and history does not appear to record their inventor.) For packing James Watt tried at different times, leather, felt, horse manure, and finally his own hat! Until Maudslay invented the lathe-slide about 1820, true turning was so rare that serious experiments were carried out with square pistons and cylinders.

Gears were laboriously filed by hand, and it was always explained to buyers of the new machinery, that the excessive noise would get less as the gears wore themselves in! Milling machines were unknown until about 1835, shapers and planers came a little earlier. In those days, little work was done to gauges and templates, and blue-printing was unknown.

Towards the end of the nineteenth century the "millwrights" who had been accustomed to making the whole contraption in the workshop, and then carting it off to erect and set going (Watt's first engine was erected at Bedworth), had been replaced by men skilled at one trade, engaged on more-or-less repetition work, and whose work was subject to inspection, usually by the foreman. Matthew Boulton probably started it when he built his power presses in Birmingham to make the new coinage, and was so pleased because not only could they turn out 300 components an hour, but "boys of 12 years may conveniently work them". The ghastly results, to the boys, in an age when power-press fencing was unknown and the first Factory Act had yet to be passed, will hardly bear thinking on.

Oddly enough, coins are the one product which nowadays are not inspected at all in the true sense, being weighed, counted and measured entirely mechanically, with the rejects just falling out by the wayside. In the years that have passed between, fine measuring has become an art. Inspection has become a skilled "trade, profession or occupation", as it says on your Income Tax form, and precision gauges change size when you breathe on them.

But these developments are really modern and not history – as the old professor said to the Yank in the film, A Yank at Oxford:

"Sir, you cannot write about the history of America – there isn't any."

To many inspectors, inspection signifies merely the examination of parts to determine whether they fulfill the size specifications of the manufacturer or of the government. In reality, inspection has for its objectives the continual maintenance and improvement of quality. The term "quality" denotes at least four equally important aspects in the examination of material. They are:

1. *Dimensional Inspection*
   The examination of a part which is made to function with component parts in an assembly.
2. *Physical Properties*
   The testing of the internal structure of the material to determine homogeneity and its resistance to the stresses and strains to which it may be subjected in service.
3. *Visual Inspection*
   For surface quality and general workmanship.
4. *Final Inspection*
   To determine that the various parts and components are assembled correctly and that the final product functions properly.

When these fundamental aspects are understood, it is readily apparent why skilled aircraft inspection requires constant and diligent application on the part of the inspector.

PRESENT

Now, "to err is human – to forgive divine". Far from expecting any God-like divinity in present day inspectors, they exist for the purpose of finding the mistakes of erring humans and machines. It may be that those humans sometimes think of inspectors as being less than men, and indeed some have had the gall to even say so – out loud – but on the other hand, the aircraft industry, and all people who fly, have much to be thankful for in the way these same inspectors carry out their exacting tasks.

Just as it is human to err, so it is also human to enjoy pointing out the other people's mistakes. The good inspector, however, overcomes this weakness and regards his job as being to look for the things he can accept, rather than looking for what he can reject. There is a world of difference between those attitudes; one is destructive and the other is constructive. Proper inspection is, therefore, a constructive job in this modern mechanised world.

This is probably best shown by a comparison in another field – we all know the newspaper copy reader. His job is not so much to point out the mistakes of the compositor as to ensure, as far as possible, that the paper says what it means to say, to prevent "Battle scarred veteran" from becoming "Battle scared veteran", and in more serious cases to save his paper from libel actions.

On the other hand, there is the man in the street who feels that any hole being dug in the road is a

personal matter, to be examined at great length. His judgment is nearly always a criticism of the men digging the hole, and his inner feeling is that he could do it better. It's too bad he doesn't try it sometime.

The modern inspection department is usually, in the aircraft industry at any rate, under the control of a chief inspector who, whilst he is just as interested in production as any other senior executive in the organization, is independent of the purely production side and is responsible to a senior member of the firm not solely interested in quantity production, perhaps as the chief engineer or the managing director. The principle underlying this arrangement is, to put it briefly, and bluntly, that it is considered unwise under modern conditions to allow a production unit to "mark its own copybook."

As previously stated, the inspection department, as part of the works organization is just as much concerned with production as any other section, but their job is concerned with quality particularly, in addition to quantity production, and it would smooth the paths of all concerned if this was more fully realised by production and inspection alike. The inspector who carries out his job in the frame of mind that he has no interest in production quantity and the foreman who thinks of inspection just an any unnecessary evil which has been thrust upon him and as an obstacle to be overcome, are equally out of place in any well-regulated factory organization. Production and inspection alike are sections of an organization which exists for the purpose of producing work to the *quantity* required by the production programme and of the *quality* required by the contract and/or by the firm's own standard. Between inspection and production there should be a clear and mutual understanding of the other fellow's point of view if that co-operation is to exist, which will produce the results which their employers have a right to expect. I have stated that the inspection department is responsible that the quality of the product is such as to satisfy the requirements of the contract and also the standard laid down by the firm for its products. In a well organized factory where a good standard of quality is aimed at as a matter of principle, inspection has a straight-forward job. There are, however, instances where modern production methods beget a tendency on the part of the production officials to press for the most expedient manufacture without worrying unduly about quality so long as the articles they are producing will not be rejected by inspection. The factor of quality is thus often regarded by the zealous production official as being of secondary importance and of being in any case the responsibility of inspection, the assumption apparently being made that the existence of an inspection department absolves the production side from all responsibility for quality. This attitude is wrong; it is unfair to the employer and it has a thoroughly evil influence on production output causing delays and dislocation in the production line and increasing very considerably inspection times and costs.

The decline of craftsmanship and pride in workmanship due to bonus systems, mass production, and, during the past few years, labour dilution, sets many problems in an inspection organization and it does not make the task any easier if the production man is constantly and consistently working on the border line of rejection. In these circumstances, the inspection department, which has no control over the factors which govern quality, can keep it up to the required standard only by rejection and demands for adjustment, an expensive method of achieving the objective and one which is fundamentally and entirely wrong. It should not be necessary for inspection to be continually battling to obtain the standard of quality, which is, or should be, just as well known to production as it is to inspection. In my view the production departments should plan to produce work not only to satisfy the programme in respect of quantity, but also with as much regard to quality as they would have if there were no inspection to check up and take the responsibility for this important factor. It may be argued that this is a policy of perfection and that if this condition were attained there would not be any need for inspection at all. I agree entirely and I consider that it is an ideal to be aimed at. This degree of perfection, however, is not likely to be reached under present day conditions, but if it is kept in mind and worked towards as an ideal, not only will the job and cost of inspection be greatly eased, but production will benefit by reduction of the delays which are caused by abnormal inspection times and by dislocation of shop routine due to rejections, adjustments and replacements. It has often been a source of amazement to have a production official complain about abnormal inspection times which were directly and entirely due to the shortcomings of his own section in submitting work in the condition which made necessary such inspection times. It is quite true to say that if the quality of the job is not up to the required standard the job is *incomplete* just as much as if it had been submitted minus some of its component parts and the responsibility for the delay incurred thereby lies, not with the inspection, but with the producing unit. In this connection I am reminded of the wisecrack of an industrialist who said: "There are two ways of getting no output; one is to make nothing and the other to make scrap, the former being the less expensive of the two".

FUTURE

Now, what of the future? The increasing demand for precision and interchangeability compels those of us who are active inspectors to consider some of the latest inventions and innovations which are likely to reduce our own usefulness. First, take the die-casting industry. Scientists have given us suitable alloys and engineers have acquired the technique of producing remarkably accurate components in great numbers and at little cost. Pressure moulding has brought great steps forward in producing these castings absolutely alike within very close limits and figures like .001 inch and .002 inch are not impossible. Furthermore, these can be taken, literally straight from the foundry and assembled on the aircraft, or on the automobile. Little or no inspection is required and large quantities are now produced without it.

Another industry is now with us that is destined to affect the future of inspection — the plastic industry. Here again, once the die is set, thousands of components follow each other exactly alike, and need only superficial cleaning before being assembled into panels and brackets,

etc. Many methods are being exploited for adapting plastic components to suit engineering requirements, such as metal re-inforcements and the use of laminated wood impregnated with the material.

The application of this structure in aircraft is well known. What is to follow? Furniture and even coffins are now being made. Who is to say what the limitations of this technique will be in the future?

Coupled to these and other practices, amazing results have been achieved in the U.S.A. in exploiting mechanical inspection and looking into the future it is now easy to visualize machines being designed which will inspect their own products.

However, even with all our modern inventions, I don't think we will live to see the day when an aircraft will be self-inspecting. Engineering and Production will take care of that for us.

Nor can I see anything in the foreseeable future that will in any way affect the vital position that the industrial inspector, and the aircraft inspector particularly, now finds himself in.

Foremen, workmen, and management are increasingly recognizing that the inspector is not a professional "fault finder", but is necessary in any works organization to ensure that a product of consistent, high quality is manufactured, in the least possible time, with the least possible trouble to all concerned.

The inspector is a specialist engineer, and as such has a few foundation stones on which to build his career, and upon which a structure of real value can be established, proving to the engineering world the importance of inspection in its efforts to control quality in the sense of guarantee. These are:

(1) The first duty of an inspector is to minimize the possibility of problems arising by helping production to present for inspection a correct article.

(2) To create harmony and co-operation with supervisors in order that the inspector's approval is recognized as the company's guarantee.

(3) To be prepared at all times to justify his decisions.

(4) To conceive that quality is created by efforts of supervision over the operator, but that quality is controlled, in line with the company's guarantee, by the inspector.

If these foundation stones are built upon with right desire and continuous thinking, problems will cease to have scope in the inspector's experience, and when they do arise, will be looked upon as ladders, lifting one's thoughts to higher planes and making inspection, in reality and cold fact, an insurance policy through which a manufacturer guarantees his product to the public.

NOTE:

The Address of C.A.I. Headquarters

Now Is

COMMONWEALTH BUILDING

77 METCALFE STREET

OTTAWA 4

A CASE FOR SMALL TURBINE ENGINES†

by J. J. Eden*

Trans-Canada Air Lines

To develop a gas turbine from the drawing board to acceptance runs involves a minimum investment of some 15 million dollars. No wonder, therefore, that the number of different types of engines designed and developed to the running stage has been very small. When so much is at stake, the importance of the initial engine specification is self evident. Since the gas turbine is mainly used for military applications, the size of a country's gas turbine industry is proportional to the funds available from the taxpayer. The smaller the population or national product of a country, the more critical the decision as to the type of gas turbine–if any–that should be designed, developed and put into production.

In a country such as Canada, where only one original type of turbine has been under production at any one time, the engine specification is directly related to the requirements of the aircraft which it is to power. This, in turn, must be designed with a view to military strategy, both domestic and international. It is outside the scope of the ability of the writer to discuss problems as complex as those resulting from overall strategy; however, the temptation of going through the stages of the exercise of choosing an engine which would give optimum returns for the tremendous public investment is too great to be resisted.

Table 1 groups the engines, on which data has been published, into thrust categories. Figure 1 gives the thrust trend against years, and Figure 2[1] shows the variation in Weight/Thrust ratio against engine thrust averaged over engines produced.

It will be noted that the great majority of engines made so far give more than 6000 lb. thrust. Engine thrust is continually increasing and the general trend has been towards larger engines. It may safely be assumed that engines in the 15-20,000 lb. thrust class are presently under development in a number of firms.

A number of engines of smaller calibre have also been produced, but these have clearly not yet received the measure of support given to engines of larger thrust. Table 2 presents a list of small gas turbines for aviation use, and typical examples are shown in the various views of Figure 3. The manufacturer and engine performance data, are given in the table.

TABLE 1
Thrust Categories.

Thrust	Percentage
0 — 1000	10
1000 — 5000	20
5000 — 10000	53
10000 — 15000	17

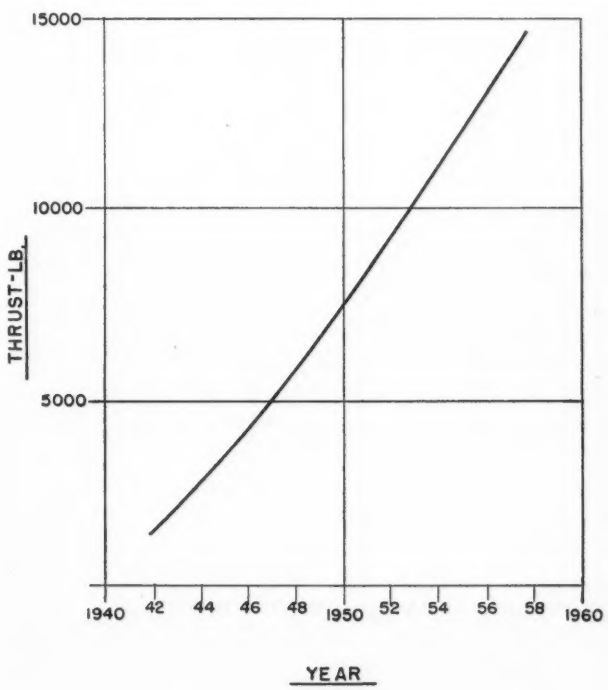

Figure 1

Maximum thrust achieved vs. years

†Received 18th July, 1955.

*Senior Engineer

TABLE 2
Small Gas Turbine Engines for Aircraft.

No.	Manufacturer	Designation	O/D Inches	Dry Wt. Lb.	Max. Thrust Lb.	Sec. Lb./Lb./Hr.	Fr. Area Sq. Ft.	Thrust Fr. Area	Weight Thrust
1	Westinghouse	J-34-WE-34	24	1233	3250	1.06	3.14	1035	0.38
2	Fairchild	J-44-R-12	22	363	1000	1.65	2.64	379	0.303
3	Armst.-Sidd.	Viper ASV 3	24.7	375	1640	1.09	3.32	494	0.229
4	Armst.-Sidd.	Viper ASV 5	28	465	1640	—	4.31	380	0.284
5	Rolls Royce	Soar	15.8	275	1810	—	1.37	1326	0.152
6	Bristol	Orpheus	32	850	5000(?)	—	5.57	900	0.17
7	Turbomeca	Palas	16.1	159	350	1.10	1.41	248	0.454
8	Turbomeca	Marbore II	22.3	293	880	1.08	2.72	328	0.333
9	Turbomeca	Aspin	23.8	304	800	0.52	3.11	257	0.38

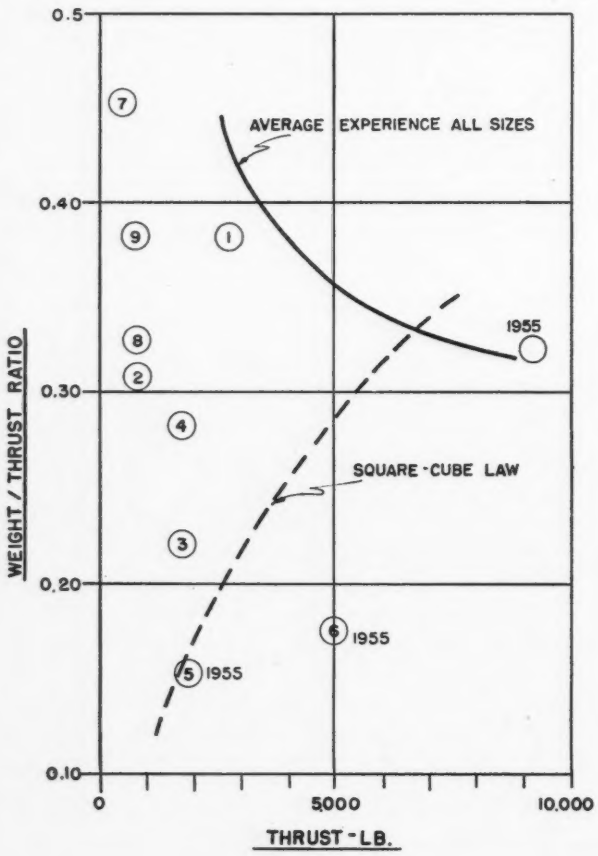

Figure 2
Weight/thrust vs. thrust

It will be seen that the French gas turbine industry in particular has adjusted itself to the financial problems involved. It has found a field suited to local capabilities where ingenuity applied to design and production has given both original and rewarding results. The variety of engines produced by the relatively small firm of Turbomeca (Figure 3a and 3b) shows the flexibility of application of the small turbine. The detail design of this family of engines differs greatly from that of large turbines. The engines have been designed as small turbines from the start, allowing simplification of many components from both a functional and production point of view.

The Rolls-Royce Soar (Figure 3c) demonstrated in flight at last year's Farnborough show is an example of the improvement in weight-thrust ratio that can be achieved from a small gas turbine. The engine appears to have been designed for a special application, and specific fuel consumption could probably be improved at a sacrifice of other factors, if required.

The Armstrong-Siddeley Viper (Figure 3d) was used soon after the war as an expendable unit powering the Jindvik target plane. The performance of the Viper should therefore not be considered as a typical example of current small gas turbine achievement. The experience with the initial design led to the development of the "long-life" Viper. This has considerably advanced the introduction of the Folland Midge which recently passed the speed of sound. This prototype is soon to be followed by the Gnat powered by the Bristol Orpheus which is believed to be in the 5,000 lb. thrust class. This engine should give proof of the performance benefits to be gained from applying latest design thinking to a small gas turbine.

The presently neglected thrust range of 2-5000 lb. would appear to offer great possibilities to a Canadian designer and manufacturer of gas turbines. Let us investigate the advantages a small gas turbine would have over turbines of larger thrust.

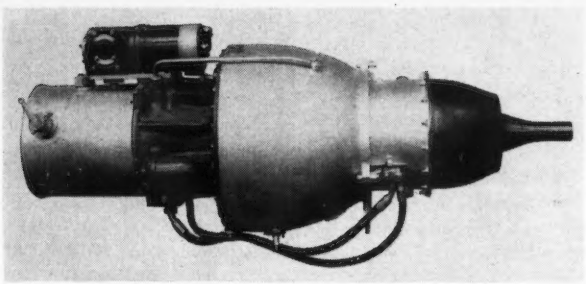

Figure 3a. Turbomeca Palas

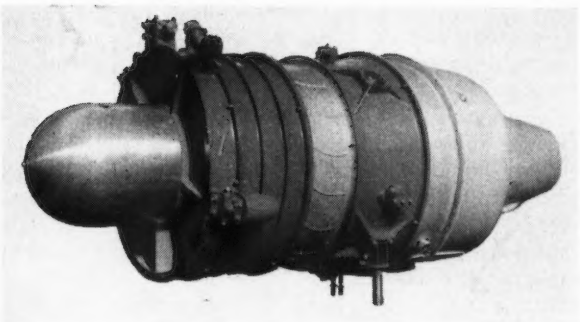

Figure 3b. Turbomeca Aspin II

THRUST

Theoretically, the thrust of a gas turbine varies as the square of its diameter, the weight varies as the cube. If we were to take a 10,000 lb. thrust engine and halve its diameter, then theoretically we should obtain an engine of quarter the original thrust, but weighing only an eighth of the original engine weight. Four of these small engines would give 10,000 lb. thrust, but their total weight should only be half that of the single 10,000 lb. engine.

In practice, this theoretical square-cube law does not hold exactly for "scaled" engines due to scale effects and limitations, such as metal sheet thickness, machining, minimum length of combustion chambers, etc. If, however, the engine is designed as a small engine from the start, the weight returns will be better than those indicated by "scaling" the dimensions of a given large engine. The process of dimensional reduction is limited, giving a minimum size design compromising between weight reduction and optimum performance.

A comparison between existing designs and the theoretical curve for the square-cube law is given in Figure 2. From the identification of the engines, in Table 2, it will be seen that as the art of small gas turbine design is developing, so the results tend towards the "present day" theoretical curve.

DRAG

The Power Plant drag depends on the frontal area, as does the thrust of the engine. Since both drag and thrust vary as the square of the diameter, there would be no reduction in drag where the thrust was obtained from a number of small engines if these were exposed to the air-stream as in a pod installation. In fact, in such an installation, the drag would tend to increase with the increase in the number of engines, since accessory equipment could not be decreased in size in proportion to the engine. The bigger drag per unit thrust of the podded design may still be outweighed by the advantages of simplified installation and serviceability.

However, in a wing installation, the power plant drag would be considerably decreased by bringing the maximum engine diameter closer to the actual design wing thickness required. In this case also, the complications, associated with the location of exhaust pipes of buried engines in respect to the main spar of the aircraft, would be reduced by reducing engine size.

A further consideration in the choice between podded and buried engines is the greatly reduced resultant effect in the small engine case, of a critical component failure, such as a turbine disc. Aircraft with small engines could be designed in such a manner as to assure that a disc failure, even in a buried installation, should not be followed by catastrophic results.

WEIGHT

The main advantage of small engines is the reduced weight for a given thrust. For a given design, a reduction in engine weight will be reflected in an accompanying reduction of supporting aircraft structure starting a cycle of weight reduction which will result in shorter take-off and landing runs and higher speeds for the same thrust and payload, or a higher payload or a longer range for the same thrust.

SPECIFIC FUEL CONSUMPTION

The specific fuel consumption of small engines is presently higher than that of large engines; however, development and an individual approach to small engine design should bring about considerable improvements.

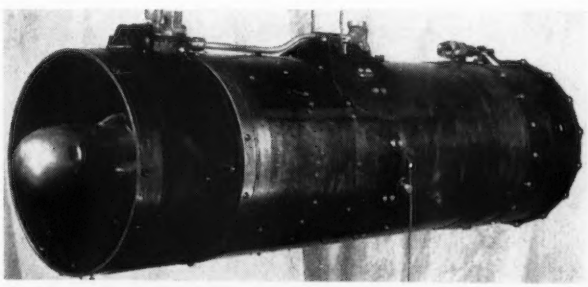

Figure 3c. Rolls-Royce Soar

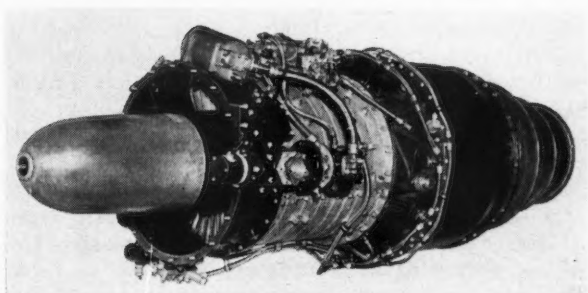

Figure 3d. Armstrong Siddeley Viper

PROJECT AND DESIGN

The small engine affords many design advantages, some of which are given:

Starting

The polar moment of inertia of the engine is proportional to the mass and the square of the mean radius. Where the mass varies as the mean radius cubed, the polar moment varies as the fifth power of the mean radius. The polar moment is, therefore, considerably reduced for small engines, and the starting power requirements are similarly reduced.

Casings

Engine casings transmit the loads from the bearing supports to the engine mounts. With the small rotor weights considered, casings can generally be of sheet metal construction giving simpler and lighter structures.

Bearings

Small rotor weights and small diameter shafts enable the use of reliable bearings operating at low track speeds.

Compressor

A small engine diameter enhances the possibility of utilizing a centrifugal compressor with its production, maintenance, reliability and overhaul advantages. The centrifugal compressor, however, will not provide the high compression ratios required to obtain a low specific fuel consumption, and where this requirement outweighs the above advantages, an axial compressor may have to be used. Axial compressor blades are usually mounted in discs carried on a shaft. As the blade hub radius is reduced, and as difficulty in machining sufficiently thin discs is experienced, so it becomes more economical to carry blades on ring drums. A drum arrangement is not only proportionally lighter than a disc arrangement, but also greatly simplifies production. Spacers may also then be made as part of the drum, reducing component parts and tolerance build up. In a drum construction, the blade load may be carried by the drum, only requiring a light tie shaft.

Turbine

Large gas turbine engines are made with increasing numbers of turbine stages necessitated by a limiting turbine radius and a large compressor power requirement. The complexity of multistage arrangements is increasing. The small engine should enable the designer to extract the required power in one or two turbine stages.

Blades

With small dimensions, simplified methods of blade fixing may be applied.

Cooling and Pressure Balancing

The problems connected with cooling of components and pressure balancing of the engine are greatly reduced with small engines.

PROJECT DESIGN FLEXIBILITY

Small engines lend themselves to various applications with much greater flexibility than large engines. Thus, a basic design could be developed into a turboprop, free wheel or fixed wheel, a straight jet, single spool or twin spool, or a by-pass engine with a high degree of interchangeability.

A reduction in the number of components will result in reduced project and design times, and would enable better co-ordination and concentration of effort. The important period from project to production should thus be shortened.

DEVELOPMENT

The gas turbine engine is highly sensitive to component efficiencies. These must be optimised by lengthy rig testing and development. To test large components requires extensive installations and a considerable power supply. The smaller the components, the smaller the requirements. Concurrent rig testing of a number of the same small component should be less expensive and entail less complication than the testing of a single large component. Rig development of smaller components should, therefore, cover a shorter period and require less costly equipment.

PRODUCTION

Successful production is based on large production orders. Modern tooling methods for mass production are too complex and expensive to be installed for small production runs, and must be justified by the number of products envisaged, but their installation will bring about fast output, good component interchangeability, reduction in scrap, minimization of manpower, utilization of unskilled labour, and a reduction in unit costs.

Where mass production methods are applied to a relatively small number of units, design and development changes introduced during production would result in expensive tooling changes increasing unit costs. A system producing large numbers of units is not as critical to such changes and will absorb these over the large production run. The designer and development engineer do not face the same production deterrent in this case and the end product will, therefore, be to a higher development standard at any one time.

In particular, countries limited to the production of a small number of aircraft will gain from large engine production runs.

In addition to the advantages of mass production, the reduction in finished weight per unit thrust results in a similar reduction in raw material requirements. Since many strategic materials are involved, the effects of such savings are significant.

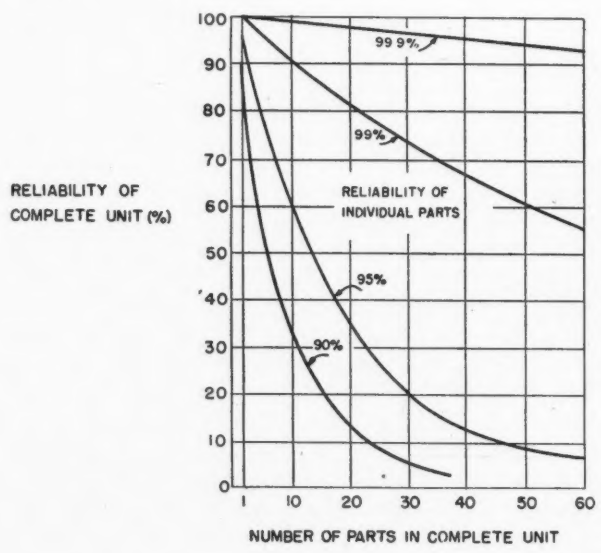

Figure 4

Reliability as a function of number of parts

Due to the reduction of the number of different components involved in providing a given total thrust, the man-hour requirements for an equivalent small-turbine programme should be below the man-hours required to produce a smaller number of larger units giving the same total thrust.

INSTALLATION AND CONTROL

The installation and control of a large number of engines in an aircraft is considered the main deterrent to the general application of small engines. Certainly, controlling, for example, eight or twelve engines by present conventional means with equivalent multiples of single engine controls and instruments would be impractical. A design approach in line with recent advances in automation should provide controls and instrumentation of a level of simplicity comparable at least to present cockpit lay-outs.

Reliable automatic temperature and speed control should enable the elimination of the actual indication of these variables from the cockpit, possibly leaving fuel flow as the only indicated engine parameter. Where a large number of engines is involved, multi-indicator instruments could be used, since once a required average performance is established, within given tolerances, it is the scatter between engines which is significant rather than the performance of the individual engines. Should an engine be malfunctioning in respect to temperature or speed, then a warning light could draw attention to that particular engine. Means of stopping any one engine automatically or manually could be provided. A number of engines could be controlled by one control lever in the cockpit. Starting could be effected by selecting the respective engine, and pressing a common starting button.

The above are mere suggestions implementing the belief that the problems presented by small engine utilization are surmountable. An actual requirement for simple control and instrumentation of a large number of engines would inspire new trends of thought and approach. The automation engineer has shown his capabilities in many fields. With him rests the responsibility in times of emergency to automatically guide highly destructive materials in the required direction only. Such faith could not be surpassed by entrusting him with the safe automatic control of the power plants of the civil and military fleets.

RELIABILITY

The reliability of a complete unit depends both on the number of components in that unit and their individual reliability. (Figure 4[2]). Small engines offer scope for reduction in the number of components per unit: compressors may be centrifugal or feature a small number of axial stages with a correspondingly small number of blades. The number of turbine stages and blades will be similarly reduced. Combustion systems can be simplified leading to a reduction in fuel lines, burners and igniters. The reduction in number of other components will follow. For example, the British Orpheus is reputed to have two rotor shaft bearings only.

The chance of any single malfunctioning on an aircraft fitted with a large number of engines is increased

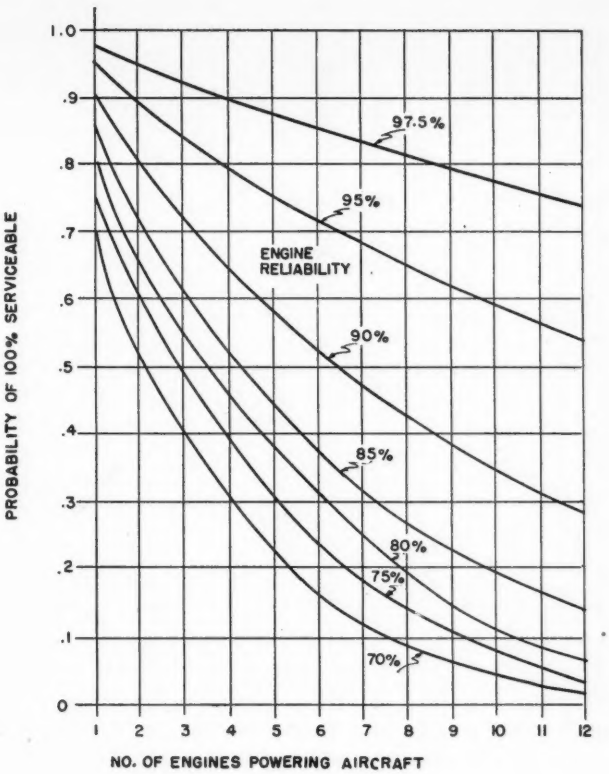

Figure 5

Chance of all engines being serviceable with varying engine reliability for different number of engines powering aircraft.

when compared to an aircraft with fewer engines, if the same engine reliability is assumed. The practical effects of the malfunctioning on the total performance of the aircraft are however reduced in the multi-engine case. Figure 5 shows that the chances of no failure on all engines are the same for an aircraft powered by twelve engines with a single engine reliability of 96.5% as for one with four engines with a single engine reliability of 90%

Even neglecting the improvements in reliability to be gained from engine simplification and reduction in engine component numbers, the chances of say three engines or more out of twelve failing on any one flight are smaller than the chance of one or more engines out of four failing, as can be derived from Figure 6.

In both cases, 25% thrust would be lost. The chances of three out of twelve engines failing at the same time, for example during take-off, are negligible compared to the single engine failure at take-off, and the chances of the three engines failing on the same wing are equally small.

Small engine operation will thus tend to increase aircraft reliability.

APPLICATION

Civil Operators

The availability of small engines should enable the operator to standardize engines in his fleet of aircraft. The greatly reduced small engine weight for a given

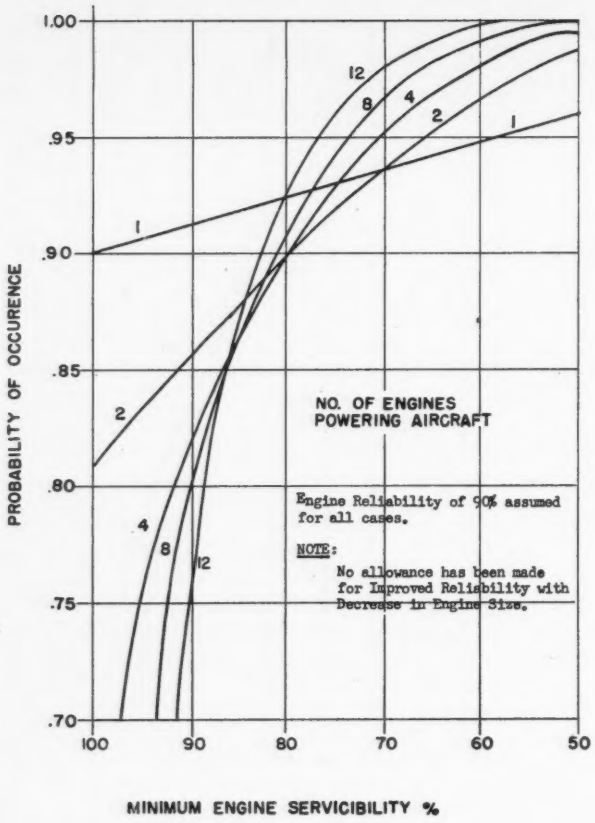

Figure 6

Probability of given percentage of engines being serviceable

thrust will result in increased payload, speed or range, or a compromise improvement between these factors. The actual reliability of a flight will be improved when a large number of small engines power an aircraft.

The significance of a single engine failure is reduced as the number of engines powering an aircraft is increased. A change in mandatory requirements specifying the percentage thrust that must be available instead of the number of engines operative should be introduced. This would enable the operator to continue a scheduled flight in case of a certain percentage of engine malfunction until a convenient base is reached where an engine can be changed without causing an aircraft delay.

Due to the reduced unit cost of small engines, more stations could be provisioned with spare engines for the same capital investment giving a more flexible operation.

The problems of line maintenance should not increase in proportion to the number of engines powering an aircraft. The number of aircraft fuelling points should be the same irrespective of the number of engines, and a change in design practice giving a common oil system for a number of engines should maintain a low number of oil checking points. The reduced significance of an engine failure, the concentration of engine changes to certain convenient points, and a simple engine change design, should actually decrease line maintenance problems and provide a more reliable operation with fewer delays.

With the use of small engines, the number of units passing through overhaul would increase. Further, standardization of engine type in a diversified aircraft fleet will bring about a large overhaul flow of the same unit which is conducive to considerable reductions in overhaul costs. Present A.T.A. methods of overhaul cost evaluation derive a linear variation between engine weight and overhaul costs. On this basis, the total overhaul costs per unit thrust would be minimized by minimizing the weight/thrust ratio as is done by the use of small engines.

Military

There is a clear field for small gas turbine application for military uses both for training and operational purposes. Particularly in the case of the long range defence or attack plane, small gas turbines show many strategic advantages. Where the defence of large land masses is involved, the problems of modern warfare requiring rapid action by accurately guided missiles are accentuated. Where the number of land-missile stations would be too large to give first line defence, the requirement exists for "missile-carriers" equivalent to the aircraft carriers of the sea. Such aircraft should be able to carry a large weight of missiles, cruise for long periods in a given area, and move with great speed to a zone through which an enemy is travelling. The aircraft would not have to engage the enemy bodily, but should carry on all the action by means of the missiles released and guided from the aircraft. The actual speed altitude requirements of such a carrier would give it great advantages over the presently specification-wise overburdened long range figher. Small gas turbines would appear to be the best power plant for the aircraft. All the engines available could be used for take-off and climb. For purposes of patrolling at low cruising speeds, a number of engines could be closed giving maximum endurance flight. In case of need, these engines could be re-lit and the aircraft could proceed at maximum speed to the scene of the engagement.

Private Flying

With the development of small gas turbines, the field of applications widens rapidly. The small executive, private or short-haul plane could be powered by the same basic type of engine as the large civil aeroplane or the long range missile carrier. The small or private operator would thus stand to gain his share of the overall developments in engine design.

NEW APPLICATIONS

Helicopters

Present helicopters only offer a low percentage payload of all-up weight. With small gas turbines propelling blades, the weight reduction achieved for a given available power can be utilized to increase the payload, making the helicopter more economical over certain stage lengths. A number of small engines driving a rotor would improve present day helicopter reliability. The rotor speed requirements during take-off when compared to those during cruise are such as to make a free wheel turbine well suited as a propulsive unit for helicopters.

Assisted Take-Off and Landing

The take-off regime is generally the maximum design criterion for the propulsive system. To assist the take-off, a number of small gas turbines could be used in a number of combinations where either the engines themselves or

the mass flow are aligned in the required direction. The same means may be used for shortening the landing run and, thus, vertical take-off and landing or a reduction in runway length for both cases may be achieved. Conversely, where sufficient runway is available, the payload or all-up weight may be increased.

The low weight/thrust of the small gas turbine make it well suited for this application.

Boundary Layer Control

Certain aircraft of the future will utilize boundary layer control for take-off, climb, cruise and landing. Circulation control, increasing the lift-coefficient during take-off and landing, is especially suitable for short-haul aircraft. Laminarisation of flow by boundary layer control, whether partial or complete, gives optimum returns when applied to the long range civil transport or the long range military aircraft, such as the missile carrier which could be operated sub-sonically in the maximum endurance regime whilst patrolling. A sharp reduction in unit power output requirement accompanies the concept of the laminarised aircraft.

The small gas turbine, particularly the by-pass type, is well suited to act as an air pump for circulation control or to drive suction-blowers for laminarisation. With small dimensions, engines or their components can be installed in the respective energized aircraft surfaces and can give an even distribution of suction and blowing whilst minimizing duct losses.

Other Applications

The construction of a basic type of small gas turbine could lead to developments resulting in both thrust increase or decrease. The experience acquired by small engine design could be utilized in further applications such as the design of gas turbines for the drive of aircraft accessories, engine starter units, etc., as well as general applications for air, water or hydraulic pumps. Further, the creation of a small gas turbine industry could lay foundations leading to the development and accelerating the introduction of the gas turbine for road, rail and water transport.

CONCLUSIONS

The main advantage of the small gas turbine is the resultant small weight for a given thrust. The application of small gas turbines to aircraft will result in an increase of payload, speed or range, or a compromise between these aircraft design variables. The small gas turbine concept brings with it associated advantages in project, design, production and versatility of application, resulting in a reduced cost per unit propulsive thrust produced.

There is a large field of application for small gas turbines including civil, military and private uses.

Airlines operating over a diversified route structure with small, as well as long stages, would benefit from engine standardization in the number of various sized aircraft required.

Missile carriers, designed under simpler specification requirements, powered by small gas turbines enabling efficient operation through a range of aircraft speeds are advantageous, particularly for the defence of large land masses.

The powering of helicopters and small aircraft for commercial and private flying, with basically the same engines as used by the military and large civil operators, would, in addition to improving performance and reducing prime costs, give the small operator the benefits of large scale production and a share of the total operational experience.

The application of the small gas turbine to aircraft is compatible with envisaged developments such as assisted and vertical take-off and landing, boundary layer control, and latest requirements of auxiliary systems.

The foundation of a small gas turbine industry may accelerate the development of gas turbines suitable for a number of other applications.

This country in particular, with a relatively small aircraft industry, limited number of each specialized aircraft type, airlines with diversified aircraft operating over routes from 50 to 3000 miles, a large land mass with a vast defence line separated from populated areas, an ever increasing utilization of small aircraft and helicopters, would benefit from the early development of a Small Gas Turbine Industry.

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AERIAL SURVEY OPERATIONS†

by J. Fleming*

Spartan Air Services Ltd.

SUMMARY

Growth of the Spartan Organization, from its formation in 1947, is outlined. Various types of aerial surveys are described, from the short-wave radio-activity surveys to the Shoran tri-lateration work and magnetic surveys. The aircraft types used in the survey work are discussed and include Avro Ansons, Cansos, Venturas, P 38's, and Mosquitoes. The dependence of aerial survey operations on weather is stressed and operational techniques are discussed. The qualifications required of personnel engaged in aerial surveys are discussed.

I PROPOSE to deal principally with the ways in which aerial surveys operations differ from other flying operations. To begin with, the airborne phase of aerial surveying is just one link in a long chain of events joining a requirement for information at one end to the satisfaction of that requirement at the other; I shall deal only with the phase involving aircraft operations.

GROWTH OF SPARTAN ORGANIZATION

Before discussing our operations, a brief history may be in order. Spartan Air Services Limited was organized in 1947, and began operations the same year with a survey fleet of two war surplus Mk. V Avro Ansons, equipped with war surplus K.17 aerial cameras converted to mapping cameras and manned by war surplus personnel. The president and chief pilot was John Roberts; R. L. Hall, secretary-treasurer, doubled as navigator when administrative duties permitted and J. Kohut, DFC, was chief navigator. They were joined by the late E. M. Benoit, a skilled photo-navigator. All four had seen wartime service in the RCAF as had most of the other members of the small staff. By 1949, Spartan had earned an excellent reputation for survey photography, to a great extent based on the remarkable skill in photo-navigation of Kohut and Benoit.

By 1950 it was apparent that it was desirable to enter the field of mapping from aerial photographs. Experience in this field was lacking among Spartan personnel; accordingly, negotiations were concluded with Aero Service Corporation of Philadelphia, resulting in the formation of Canadian Aero Service Limited, now one of Canada's leading private mapping organizations and a partly owned affiliate of Spartan.

From very modest beginnings we have grown to the extent that our fleet now consists of a total of seventeen fixed wing survey aircraft plus twelve helicopters and several support aircraft, and our permanent staff exceeds two hundred persons.

TYPES OF AERIAL SURVEYS

When you mention aerial surveying many people tend to think only of aerial photography, and it is true that the bulk of our work at Spartan consists of vertical photography for mapping. We shall consider mapping photography in greater detail later. But there are several other types of survey work which we carry out from the air.

In casting about for a framework on which to hang the substance of this introduction, I could find none better than the electromagnetic spectrum to act as a skeleton to be clothed by the various pieces. At the short-wave end of the survey spectrum are the gamma radiations emitted by radio-active materials. These radiations are detectable from the air by the airborne scintillation counter. Radio-activity surveys using this instrument are frequently carried out in conjunction with other types of airborne surveys. Moving farther along the spectrum we come to ultra-violet, visible and infra-red radiations whose reflections from the earth's surface we record in the form of photography which permits us to map in great detail the visible surface of the earth including forest cover, works of man and topographic features. Next come the frequencies which we classify as radar; radiations of 1.25 cm. wavelength are bounced off the ground from an aircraft by the radar altimeter and their reflections continuously recorded to produce a profile of the ground path traversed by the aircraft; this profile is used as vertical control for topographic mapping or as a reconnaissance tool for determining locations for pipelines, power transmission lines or micro-wave links. At 1 meter we reach the wave-length used for airborne Shoran tri-lateration. This permits the electronic measurement of long lines more than 200 miles in length, using an airborne set to extend the line-of-sight distance. The accuracy of the resulting extension of the geodetic net compares favourably with that attainable by precise optical equipment, and only a fraction of the time is required to cover vast areas.

In addition to gleaning information about the surface of the earth from the air by recording variations in the frequencies of the electromagnetic spectrum emitted by or reflected from the surface, we can deduce a great

†Paper read at the C.A.I. Annual General Meeting, in Toronto, on the 20th May 1955.

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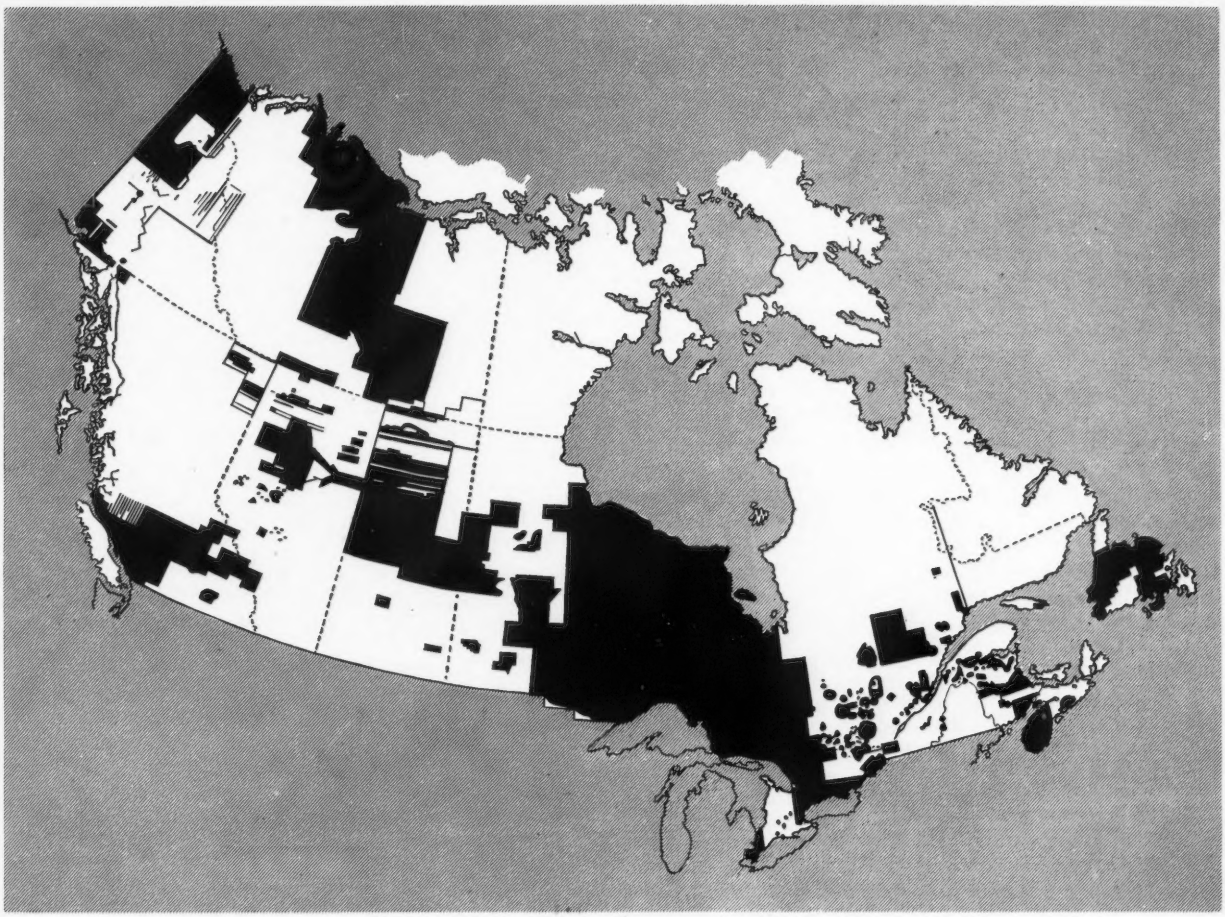


Figure 1.
Photo coverage of Canada from 1947 to date by Spartan Air Services Ltd.

deal more about the sub-surface structure also by recording the pattern of the earth's magnetic field. This is accomplished by the airborne magnetometer which produces a continuous record of the variations in intensity of the field as the aircraft traverses the area. The resulting data, when compiled into a "contour" map consisting of isopleths of magnetic intensity overlaid on a planimetric base map, is widely used in prospecting for minerals and oil.

GEOGRAPHIC EXTENT

It is perhaps unnecessary to state that our aircraft range over the whole of Canada from Newfoundland to British Columbia, and from the U.S. border to within 400 miles of the geographic pole. Just how much of Canada has been actually photographed by Spartan may be judged from the illustration of photo coverage, Figure 1. This illustrates Spartan photography alone and takes no account of the work done by our competitors or by the Air Force. It represents a very appreciable fraction of the entire face of Canada.

However, we are not confined to Canada. We have also photographed large areas of the U.S. in Montana, North Dakota, Maine and Texas. In addition, we have carried out Shoran-controlled photography in Liberia on Africa's west coast, and last winter we photographed a considerable area in British Guiana. We are prepared to carry out aerial survey work in any part of the world.

AIRCRAFT TYPES

Let us look at the types of aircraft employed to carry out these various surveys. The Mark V Avro Anson is the foundation on which Spartan's business was first built. It required little modification to make it suitable for aerial survey beyond the installation of adequate camera hatches in the after fuselage. It is safe and reliable and can be used up to 20,000 feet if necessary. It frequently is used also for photography from as low as 1,200 feet. At this altitude high speed would be a liability due to the limitations of photogrammetric lenses and films. The Anson is also employed extensively for magnetometer work. For this purpose it is fitted with a power winch to extend and retract the magnetometer bird on its 70-foot cable.

The familiar Canso has two main uses. It is well suited to magnetometer work by virtue of its long range,

low speed and the use of non-magnetic stainless steel fittings which permit the sensitive magnetometer element to be installed in a fixed position in the tail. We make use of the Canso also for logistic support to supply remote field stations where a water landing is necessary. We also employ a Fairchild Husky on floats for similar supply work involving smaller loads and shorter distances.

Venturas are used for medium altitude photography, up to about 25,000 feet, for Shoran-controlled photography and radar altimeter surveys. The roomy fuselage and load capacity permit installation of the considerable amount of electronic gear required for Shoran or radar altimetry while leaving room for a crew of up to five men. In addition, fuel capacity for very long-range work is available in the normal wing tanks, augmented by drop-tanks slung beneath the wings and a specially-fabricated fuel tank fitted in the bomb bay.

In Canada, the Lockheed P.38 is associated with the name Spartan Air Services to the extent that it is virtually a Spartan trade mark. Much of our operating success in aerial photography is due to the use we have made of this very fine aircraft. It is an excellent camera platform, being singularly free from vibration. It is a simple machine to fly, being almost completely automatic. It has first-class single-engine performance, a very re-assuring feature in view of the ruggedness and remoteness of much of the terrain over which we operate.

The P.38 as employed in World War II was a single-seater. For our purposes the nose-section has had to be extensively modified (Figure 2) to accommodate a vertical mapping camera and the photo-navigator. The modification is principally the brain-child of W. Phipps, our operations manager. It would be quite impractical to operate these complex, high-performance aircraft without the bountiful supply of mechanical genius available among the handful of fine aircraft engineers who are key men in our maintenance organization.

As we move farther north in Canada and into the Arctic islands it becomes desirable to employ aircraft with longer range in addition to high-altitude performance. For this reason we are converting to D.H. Mosquitoes MK 35. Because of the greater amount of space available in the fuselage of this aircraft, we can probably employ a three-man crew on high altitude work. We hope this course will lead to further improvement in the quality of results by enabling us to use the Wild RC5A mapping camera at high altitude. It is rather a bulky piece of equipment, weighing about 300 pounds, and could not be reasonably fitted in the P.38. These Mosquito aircraft are pressurized for greater comfort and safety.

In addition to the survey aircraft Spartan also operates a fleet of twelve Bell helicopters, forming a completely separate operating entity under the direction of J. G. Townsend.

MAPPING PHOTOGRAPHY

Let us take a more detailed look at what is entailed in carrying out mapping photography. Photography for photogrammetric mapping purposes may involve anything from taking a single pair of vertical photographs from 1,200 feet for the purpose of determining the

Figure 2.
P.38, modified for high altitude photography.

volume of a pile of pulpwood logs or of an open-pit mine, to covering 100,000 square miles completely with parallel lines of overlapping photographs from an altitude of 35,000 feet or more.

A characteristic of photo survey operations is the necessity for operating from remote temporary bases over territory which contains few places where a forced landing may be safely carried out, few weather reporting stations and few navigational aids. We sometimes find it necessary to build our own airstrip and support it entirely by air. This is currently being done in the Pelly Lake area of the Northwest Territories, where an airstrip with two 6,000 foot gravel-surfaced runways has been built. All heavy construction equipment as well as materials to house personnel and maintain aircraft, cameras and electronic equipment has had to be flown to the site by our own private airlift. Another example of complete air support is the operation that we have based at Sawmill Bay on Great Bear Lake for the past three seasons. Operating three or more P.38's out of this base in order to photograph northern Canada up to the Arctic coast of the mainland, it has been completely supplied by air from Yellowknife, some 250 miles southeast, with personnel, food, spare parts, oxygen and other necessities. Main stocks of spares are held at Ottawa, and it has been necessary to fly complete power eggs from Ottawa to Sawmill Bay on short notice in order to maintain serviceability. Support aircraft and a comprehensive and quickly available supply of spares are prime essentials if maximum utilization is to be realized.

INFLUENCE OF WEATHER

In referring to aerial photographic operations, an official of the Meteorological Service of the Department

of Transport has said, "The relationship this type of aviation bears to meteorology is perhaps unique in that the success of the in-flight operation depends almost entirely on meteorological factors".

Because of the critical weather requirements aircraft utilization in aerial photography is necessarily low in terms of flying hours per year. In most flying operations an aircraft is not likely to be grounded on account of weather more than a very few days per year. But since photo flying is dependent not only upon flyable weather but also upon the suitability of the weather for photography, we are particularly dependent upon the imponderable factor of weather for our successful operation. For instance, we have encountered in Newfoundland unbroken periods of three weeks or more during which it was not even worth while to wheel the photo aircraft out of the hangar. And many fruitless flying hours are spent searching for clear weather. Under such circumstances it is essential that when photo weather does materialize the aircraft must be fully serviceable and ready for action. Failure to make full use of the available weather may set the operation back, not just another day, but a matter of several days or even weeks until the right conditions again prevail.

It has been said that everybody talks about the weather but nobody does anything about it. This is a reflection on the Meteorological Branch of the Department of Transport which is doing something about it twenty-four hours a day. The results of their labours of observation and tabulation are published as climatological data which are profitably studied by those of us engaged in aerial survey work. This past history of weather is useful in the planning stages of an operation as an indication of what to expect in a given area. In our field operations it is the present and probable future weather which concerns us most. Here we make the fullest possible use of the weather reporting facilities of the Meteorological Service. Most of the stations in Canada which send out hourly weather reports are scattered along the airways at intervals of about 100 miles. However, most of our photographic work involves areas which are far removed from an airway. In some cases the nearest weather observing station may be several hundred miles distant. Under such circumstances we have found it profitable to establish our own weather observers in bush camps in the area we wish to photograph, linked by radio to a central point. This has been done in Northern Ontario around Hudson Bay and in the Northwest Territories in conjunction with our Shoran operations.

The forecasting of clear weather is one aspect of meteorological science that has escaped intensive study, probably due to the little economic importance of such weather to enterprises other than aerial surveying. Hurricanes, hail-storms, cloudbursts, extremes of temperature and precipitation have all received a great deal of attention and the science of forecasting these phenomena in considerable detail is well advanced. But clear, cloudless weather comes and goes quietly, marked only by a flurry of activity at the bathing beaches and at Spartan.

In fine weather the forecast offices are placid pools of unruffled calm; briefing of an airline crew may consist of a nonchalant "CAVU all the way". Into this quiet atmosphere bursts a Spartan high-altitude survey crew rudely demanding to know whether that 3/10ths of thin cirrus is at 20,000 feet as reported, or is it actually at 30,000 feet. To anyone else the answer to this question is a matter of indifference, but to us it may represent the difference between photographic weather and non-photographic weather. In spite of forecasting difficulties the forecast offices of the meteorological service have been of tremendous help to us, and our operating success is in a large measure due to the expert and willing assistance rendered by forecasters all across Canada.

It is fairly well known that our weather generally travels from west to east. It is perhaps not so widely appreciated that this is as true of fair weather as of foul; nor is it perhaps appreciated just how far it may travel upon occasion without being greatly modified en route. In 1952, for example, we were faced with extensive high-altitude commitments scattered from the Yukon to New Brunswick, and only five P.38's with which to carry out the work. We concluded that instead of placing one aircraft in each area to wait for clear weather to come to it, we should move all the aircraft from west to east with the clear weather, photographing in each area in turn as the clear air moved over that area. When the weather finally petered out, all the aircraft were to be rushed westwards again to await the next eastbound migration of clear weather. This was done several times during the season with a fair degree of success. It involved carrying a minimum supply of spare parts with us, as well as spotting supplies of spares and oxygen at strategic airports across the country and arranging for supplies of 100 octane fuel at points where it was not normally available. Ground crews were stationed at Kapuskasing, Lakehead, Winnipeg, The Pas, Edmonton and Fort McMurray to service aircraft and effect turnarounds with a minimum of delay. Fuel drop tanks were modified to serve as cargo carriers for spares and tools. One aircraft was posted to Dawson City to concentrate on the Yukon areas and the remainder formed a mobile unit whose territory covered the rest of Canada. Three of these were regular survey P.38's while the fourth was a support aircraft loaded with oxygen and spares and could be converted to a survey machine if necessary.

By operating in the above fashion we were able to discharge our commitments satisfactorily. A great deal of the responsibility for the success of such an operation rests with the field crews who must decide on their own initiative when and where to operate, the decisions being dictated by the hourly weather reports and forecasts. This involved long hours in the air daily, as many as three high-altitude sorties being carried out by a single crew on some days. But flying is the smallest part of the job; the necessity for keeping accurate records of areas covered, for correlating the work of several aircraft to prevent duplication of effort, for shifting one's base of operations several hundred miles almost daily, and for arranging accommodation for a highly mobile group of about eight men on short notice left little time for relaxation while photo weather persisted. Indeed there were actually times when an overcast day was greeted with expressions of relief. A typical log-book shows that in one six-day period nearly forty-five hours was logged out of such widely separated points as Fort McMurray, The Pas, Lakehead, Kapuskasing, Ottawa

and Quebec. During those six days, successful photographic sorties were carried out at various points between Great Slave Lake and Bagotville, all within the same area of high pressure which had been drifting slowly eastward throughout the period.

Forty-five flying hours in six days does not seem an impressive total until you realize that perhaps fifty percent of that time was spent at 35,000 feet in unpressurized aircraft.

PERSONNEL

Having considered briefly the nature of aerial photographic surveying operations, we are led naturally to consider the qualifications required of the personnel who carry out this type of work. All survey work, on the ground or in the air, involves the necessity for being in the field for long periods. Our operating personnel must be prepared to spend six to eight months in the field per year, though rarely in an unbroken stretch. They must be adaptable to changes in living conditions, and above all, must be compatible with others who will be closely associated with them for long periods, perhaps at isolated points. The prima donna type of aircrew is not welcome.

Where high-altitude work is concerned, physical suitability is important. An aircrew member cannot do an efficient job at high altitude if he is subject to severe attacks of 'the bends', or aero-embolism. This painful affliction affects some persons to a much greater extent than others. It is difficult to predict who will be more severely affected but in general overweight persons seem to suffer more than the lightweights. For this reason our high altitude crews tend to be sparely built on the average. Navigators as well as pilots are required to pass stiff aircrew medical checks regularly.

Where the type of aircraft permits we normally employ a three-man survey crew in the air, consisting of a photo-navigator who is responsible for the accurate maintenance of track during survey operations; a pilot who in addition to being aircraft captain and responsible for safety, is required to maintain constant altitude and steer accurate courses in response to directions passed to him by the navigator; and a camera operator who is responsible for maintaining the correct orientation and spacing of photographs along the survey line of flight.

Our photo aircraft are not equipped with auto-pilots, nor is the pilot responsible for the photo-navigation. In these respects our operations differ from common practice elsewhere. The photo-navigator is the key man, particularly in the P.38's where he also carries out the duties of camera operator. He is a very busy man in the air.

Where do we get men with the necessary background to make good photo-navigators? Since a high degree of map-reading skill is the foundation of good photo-navigation, and since map-reading is becoming a lost art in our modern air forces, we find it necessary to develop this skill in our navigators by instruction and practice. However our best source of supply for good raw material is still former RCAF and RAF navigators, particularly since the northward trend of our operations places a premium on skill in navigation in high latitudes. Some knowledge of the photographic factors involved and an appreciation of the requirements of the photogrammetrist or photo-interpreter are useful qualifications also.

Camera operators we must usually train completely ourselves. The term "camera operator" is used deliberately in preference to "photographer" since operation of the aerial camera is treated principally as a mechanical operation requiring little knowledge of photography, but a considerable knowledge of the precise mechanism of the modern photogrammetric camera. Personnel with the required skills are simply not available elsewhere, so we have no alternative but to train them ourselves.

For pilots we must rely principally upon ex-RCAF and RAF pilots, for this seems to be the only source of supply for young men with sufficient flying experience on high-performance aircraft. It is a great pity that many young men who wish to make a career of flying and who are willing to pay for their own tuition to the limit of their means are at a great disadvantage in competing with ex-Air Force aircrews whose expensive skills have been developed at no cost to themselves. I think there is a place in Canadian Aviation for a system of aircrew apprenticeship. It is worth noting that two of our top pilots, including our Operations Manager, are not Air Force trained, but learned to fly at their own expense.

OUTLOOK

It is apparent from the illustration of photo coverage of Canada that in a few years at the present rate we shall have met the most urgent requirements for high-altitude photography in this country. After that time we can anticipate a shift in emphasis to more detailed, larger-scale photography which will not require a fleet of high-altitude aircraft for its execution. Rather than reduce our organization to that which is sufficient only to meet domestic needs we are turning our attention abroad, to the end that we may keep our equipment and present staff gainfully employed indefinitely. There are vast areas throughout the world which badly need aerial surveys as a necessary first step in their economic development, and meeting this need will enable us to discharge an obligation to our own personnel to assure them a stable future.

TECHNICAL FORUM

LIFT AND MOMENT DISTRIBUTIONS ON SUPERSONIC OSCILLATING WINGS†

by G. C. C. Smith*

Bristol Aeroplane Company Ltd., England

THE approach of Professor Etkin in his recent paper[1] has also been in use here to determine unsteady supersonic lift and moment distribution to first order in frequency.

I hope that the following notes may prove of interest.

NOTES ON LIFT AND MOMENT DISTRIBUTIONS ON SUPERSONIC OSCILLATING WINGS

Stewartson[3] has shown the integral equation for the potential in a mixed flow region to be

$$\phi(x_1y_1+o)e^{iwt} = e^{iwt}\iint_A \frac{W(\zeta_1\eta)}{\sqrt{XY}} \cdot \exp\frac{iwM^2(\zeta-x)}{\beta^2V} \cdot \cos\frac{2w\sqrt{XY}}{\beta V} \cdot dXdY$$

$$- \frac{w}{\beta\pi V}\iint_B \frac{\phi(\zeta_1\eta)}{\sqrt{XY}} \cdot \exp\frac{iwM^2(\zeta-x)}{\beta^2V} \cdot \times$$

$$\sqrt{\frac{X_1}{X-X_1}} \cdot J_1\left(\frac{2w\sqrt{XY}}{\beta V}\right) \cdot dXdY$$

where "w" is circular oscillation frequency, and "W" is the downwash (complex). (In a "Supersonic" region the area B degenerates to zero.)

Since $J_1(\alpha) \to \frac{\alpha}{2} + O(\alpha^3)$ . . . no term of order in "w" lower than two will arise from $\iint_B$. Hence to first order in frequency we need only consider $\iint_A$.

This reduces to

$$\phi(x_1y_1+o) = \frac{1}{\pi M}\iint_A \frac{W_R\,dXdY}{\sqrt{XY}} + \frac{iw}{\pi M}\iint_A \left(\frac{W_R M^2(\zeta-x)}{\beta^2V} + W_I\right)\frac{dXdY}{\sqrt{XY}}$$

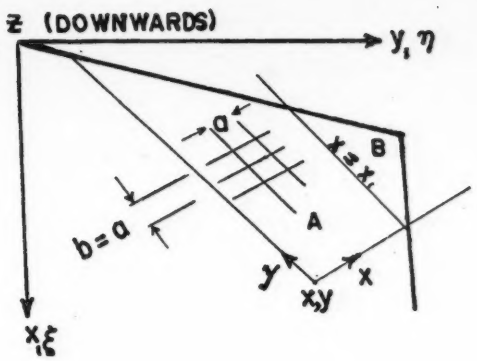
where $W = W_R + iwW_I$.

(Neglect of higher order terms requires

$$\frac{1}{2}\left(\frac{w(\eta-\zeta)}{V}\,\frac{M^2}{\beta^2}\right)^2 \ll 1.)$$

†Received 19th September 1955.

*Dynamics Group.



Proceeding in a very similar manner to Prof. Etkin we arrive at

$$\phi(x_1y_1+o) = -\frac{4a}{\pi M}\Sigma\Sigma_A W_R A + iw\left[-\frac{4a}{\pi M}\Sigma\Sigma_A W_I A + \frac{4}{3}\frac{a^2}{\pi V\beta}\Sigma\Sigma_A W_R B\right]$$

Where "a" here is that defined by Prof. Etkin and we assume $b = a$ also. Function A is identically equal to Function C of Prof. Etkin.

i.e. $A = \left(\sqrt{m} - \sqrt{m-1}\right)\left(\sqrt{n} - \sqrt{n-1}\right)$ whilst

$$B = \left(\sqrt{m^3} - \sqrt{(m-1)^3}\right)\left(\sqrt{n} - \sqrt{n-1}\right) + \left(\sqrt{m} - \sqrt{m-1}\right)\left(\sqrt{n^3} - \sqrt{(n-1)^3}\right)$$

and both have been tabulated.

However computational labour was heavy and a programme was developed by the National Physical Laboratory to carry out the summations using a digital computor (A.C.E.). Flutter calculations have been completed using this programme.

In a test case good agreement was obtained in comparison with theoretical results quoted in N.A.C.A. T.N. 2494 for a delta wing pitching and plunging in supersonic flow.

Investigations by Minhinnick at the Royal Aircraft Establishment suggest that for 16 lattice points per mean chord at M = 1.25, 8 lattice points per mean chord at M = 2.7, the accuracy of ϕ should be within 0.1% for $\frac{wC_m}{V} \leq 0.5$ and to within 0.4% for $\frac{wC_m}{V} = 1$, where C_m is the mean chord.

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C.A.I. LOG

SECRETARY'S LETTER

JOURNAL MATERIAL

At the end of September the Publications Committee held a special meeting to consider the steps which should be taken to broaden the interest of the material published in the Journal. The President and Mr. H. A. Ross, who is a member of the "Maintenance" section of the Editorial Board, came from Montreal expressly to attend this meeting. And I was there too.

First and foremost the Journal must contain material which will stimulate and interest the members of the Institute. Our members are engaged in almost every branch of aviation and only rarely will an article be of interest to all of them; usually an article will be of interest to a relatively small group and the policy is to serve as many of these groups as possible, without unduly favouring any one. I think that everybody at this meeting of the Publications Committee recognized this requirement but it was not easy to see how to get material covering so wide a range. It is not too difficult to get formal articles of value to engineering specialists in various fields; articles of value to the production specialists are also available; and we must use such specialist articles liberally. But we must also publish articles on all manner of developments and processes, tooling techniques, inspection and maintenance; and these are hard to come by.

In a Journal such as ours, our material must be our own and we must depend primarily on our members to contribute it. The Journal is a medium for the exchange of information, exchange between members of the Institute; I am quite sure that if a bunch of, say, our inspection members got together and somebody started talking "quality control", there would be a fine old argument going in no time at all. (I used to be an inspector myself and I know what an opinionated crowd they are!)

Now it's up to you. I want to emphasize that any item submitted need not be very long; one or two pages of typing and perhaps the odd picture is often quite enough to cover some interesting topic. As an example, I refer you to "R.O.R." which appeared on the lower half of page 6 in the April issue. I did not write it but I am told that it was fairly easy to write; the trick lay in recognizing it as an interesting item. It is largely a matter of observation.

TRANSFERS

It is always important that members should keep C.A.I. Headquarters advised of any change of address. It will be realized that, quite apart from Headquarters records, this advice is necessary in order that Branch records may be kept up to date.

If a member moves from a district served by one Branch to a district served by another, there is a procedure set up whereby the Secretaries of both Branches are notified by Headquarters. Provided the member keeps Headquarters properly informed of his movements, there is no need for him to go to the trouble of seeking out the Secretary of his new Branch; the Secretary of his new Branch will get in touch with him, in due course.

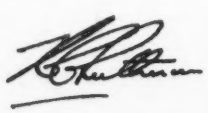
VISIT TO THE I.A.S.

I spent two very interesting and useful days in New York towards the end of September, visiting I.A.S. Headquarters. The primary purpose of my visit was to clear up any outstanding points in the arrangements for the joint I.A.S./C.A.I. meeting, which is to be held in November, but I took the opportunity to discuss several of our everyday problems – admissions procedures, publications, membership records and many others. It is not always easy to apply I.A.S. experience to C.A.I. conditions but a great deal can be learned by talking things over. Mr. Dexter and his staff were, as ever, most generous with their information and advice; I hope that in due course I can put their teaching to good effect.

NEW HEADQUARTERS

Please note the change of address; we are at last in the Commonwealth Building (Room 607). I hope that anyone attending the I.A.S./C.A.I. meeting and finding that he has time to spare from the sessions, will take the opportunity to visit our new offices. The Commonwealth Building is about five minutes walk from the Chateau Laurier, where the meeting is being held.

It might be as well to check at the registration desk first, to make sure that somebody will be there; much of the time the staff may be at the Chateau and Headquarters locked up.



MEETINGS

JOINT I.A.S./C.A.I. MEETING

A COMPLETE programme of the joint I.A.S./C.A.I. meeting to be held in Ottawa on the 3rd and 4th November appears on the next page. Notices giving further details have been sent to all members of both Institutes.

LADIES PROGRAMME

A small programme of entertainment is being arranged for the ladies. This programme will take place during the technical sessions and the inspection tour but it will not, of course, conflict with the Dinner; we hope that the ladies will attend the Dinner which is the principal social function of the meeting.

ABSTRACTS

Abstracts of some of the papers to be given at the joint I.A.S./C.A.I. meeting have been received from the authors; those received are reproduced below:—

Unique structural problems in supersonic aircraft design

F. P. Mitchell

The very rigid geometric requirements demanded by supersonic aircraft have greatly increased the complexity of our future aircraft. It has resulted in a very large increase in technical man-power required with the resulting high cost. Very thin wings, low aspect ratio wings, small diameter fuselages, high control surface loads, high pressures and temperatures, form part of the aerodynamic requirement which must be met.

The resulting structural complications are very severe. The problem of producing a sound structure of a minimum weight is discussed. Load analysis, distorted shapes, fatigue, landing gear, heat and new materials are discussed in a broad manner.

Experiment and theory in investigating the behavior of structures at high temperatures

Dr. N. J. Hoff

Problems arising from the high temperatures to which the surface of an aircraft flying at Mach numbers exceeding 3 is heated can be divided into two groups. In the first belong the problems caused by temperatures varying rapidly both in space and time and in the second those following from the exposure of structural parts to uniform high temperatures for extended periods of time. In the transient thermal state, thermal stresses develop in the structure, and often these thermal stresses cause buckling. In the steady state, creep deformations take place which change the stress distribution in the structure and can also lead to buckling. Entirely different analytical methods have to be used in the investigation of these two groups of problems. Similarly, test equipment suitable for their investigation also differs considerably. For the testing of steady state problems rather straightforward ovens can be built; on the other hand, an experimental investigation of the transient conditions can be carried out by means of electromagnetic induction heaters. Equipment developed for these purposes at the Polytechnic Institute of Brooklyn will be described and some of the test results will be discussed.

Optimum structural design of wing box beams

S. Bernstein

This paper analyses the following types of construction used for compression covers on wing box beams.

1) Skin and Z-section stringer panels.
2) Double skin and corrugation panels.
3) Solid Plate multi-web construction.

The structural efficiency of the above designs is compared on the basis of:—

1) Applied bending moment per inch width.
2) Depth of the section.
3) Minimum skin thickness required for torsional rigidity.

In addition design charts are derived for each case to help select the most efficient rib or web spacing as well as the geometry of the panel elements.

Illustrative examples are shown in which the results of this investigation are applied to four different hypothetical airplanes.

Aircraft accident investigation

G/C R. C. Davis

A number of Air Force aircraft accidents are reviewed, the investigation of which revealed features in the design of the aircraft which were incompatible with safety. Reference is made to precepts for safe design of aircraft set forth in a booklet on the subject prepared by the Daniel and Florence Guggenheim Aviation Safety Center at Cornell University.

Recent results of the N.A.C.A. crash fire research and some aspects of crash survivability

I. I. Pinkel

The manner in which the jet engine acts to start a crash-fire is described.

How the engine fire involves the entire airplane is shown with slow motion pictures of full scale test stand studies and airplane crashes. Ignition zones within the engine that start the fire are identified. Means for inerting these ignition zones are described and crash evaluation of these inerting means are illustrated with slow motion color films.

Aluminum alloys for elevated temperature service

E. H. Dix Jr.

For some years long range planners in the aircraft industry have been concerned with the effect of increasing temperatures caused by aerodynamic heating and jet propulsion on the structural materials, instrumentation and personnel. While the problem is not yet acute in today's piloted aircraft, ultra high speed craft are being designed with emphasis on the elevated temperature properties of the structural components.

The present paper describes briefly the elevated temperature characteristics of the structural aluminum alloys now used in aircraft and then presents the improved characteristics obtained in recently announced new casting and wrought aluminum alloys. Data on the new Aluminum Powder Metallurgy (APM) products, whose unique characteristics fit them particularly for elevated temperature service, are included.

Materials and fabrication techniques for structural heat-resistant plastic sandwiches

N. E. Wahl

Research on plastics has centered on developing materials and techniques for the sandwich construction of components for high speed aircraft. A review is made of the work on foamed-in-place core materials, and glass reinforced laminate skins that will maintain a good proportion of their strength at 500°F. for short periods of time.

The extension of the investigation of materials to include the fabrication techniques of a typical missile wing is outlined.

INTERNATIONAL MEETING
I.A.S./C.A.I.

Programme

November 3rd Morning

STRUCTURES

Chairman
MR. B. J. KAGANOV
Chief Structures Engineer, Canadair Limited

MR. F. P. MITCHELL
Chief Stress Engineer, Avro Aircraft Ltd.
Unique structural problems in supersonic aircraft design

DR. N. J. HOFF
Head of Dept. of Aeronautical Engineering & Applied Mechanics
Polytechnic Institute of Brooklyn
Experiment and theory in investigating the behavior of structures at high temperatures

MR. S. BERNSTEIN
Group Leader, Stress Dept., Canadair Ltd.
Optimum structural design of wing box beams

November 3rd Afternoon

THE W. RUPERT TURNBULL LECTURE

Chairman
MR. T. E. STEPHENSON
Director, Aircraft Branch, Department of Defence Production

MR. J. H. PARKIN
Director, National Aeronautical Establishment
W. Rupert Turnbull 1870 - 1954

November 3rd Evening

DINNER

Principal Speaker
THE RIGHT HONOURABLE C. D. HOWE
Minister of Trade and Commerce

November 4th Morning

AIRCRAFT SAFETY DESIGN AND ACCIDENTS

Chairman
MR. I. A. GRAY
Director of Maintenance and Engineering
Canadian Pacific Air Lines Ltd.

MR. J. LEDERER
Managing Director, Flight Safety Foundation, Inc.
Director, Cornell-Guggenheim Aviation Safety Center
Significant problems in air safety

GROUP CAPTAIN R. C. DAVIS
Director of Flight Safety, R.C.A.F. Headquarters
Aircraft accident investigation

MR. I. I. PINKEL
Associate Chief, Physics Div.
N.A.C.A. Lewis Flight Propulsion Lab.
Recent results of the N.A.C.A. crash fire research and some aspects of crash survivability

November 4th Morning

MATERIALS AND PROCESSES

Chairman
MR. H. L. EBERTS
President and General Manager, Fleet Manufacturing Ltd.

MR. E. H. DIX, JR.
Assistant Director of Research, Aluminum Research Labs. ALCOA
Aluminum alloys for elevated temperature service

MR. J. J. WALLER
Chief Materials & Process Engineer, Canadair Ltd.
The metal bonding of assemblies for the Canadair CL-28 Maritime Reconnaissance airplane

MR. N. E. WAHL
Head, Plastics Sect. Materials Dept.
Cornell Aeronautical Laboratory
Materials and fabrication techniques for structural heat-resistant plastic sandwiches

November 4th Afternoon

Tour of the
NATIONAL AERONAUTICAL ESTABLISHMENT LABORATORIES

(The tour will include an opportunity to visit the Hydraulic & Ship Laboratory, Division of Mechanical Engineering, National Research Council, where a model of the St. Lawrence Seaway will be on display.)

BRANCHES

BRANCH PROGRAMMES

The following particulars of Branch programmes have been received to date:

Ottawa

6 SEPTEMBER
"Nuclear Propulsion, Aviation's Future"
Dr. D. G. Samaras

12 OCTOBER
"The Time Factor in Aircraft Development"
G/C H. R. Foottit

3RD AND 4TH NOVEMBER
International I.A.S./C.A.I. Meeting

14 DECEMBER
(Not settled)

Winnipeg

27 SEPTEMBER
"The Problem of the Very Light, Highly Efficient Airplane"
B. S. Shenstone

The remainder of the Winnipeg programme is not settled.

Vancouver

20 SEPTEMBER
Film Night and Social Evening

11 OCTOBER
"Titanium"
O. G. Dinsdale

8 NOVEMBER
"Flying the Jet Stream"
D. Strachan

18 NOVEMBER
Social Night

13 DECEMBER
"Vickers Viscount"
B. W. Torell, E. Gerber

Montreal

21 SEPTEMBER
"Technical Aspects of Space Flight"
D. C. Romick

19 OCTOBER
Plant Visit

16 NOVEMBER
"Maintenance of Aircraft"
F/L W. F. Delaney, D. Bowen

14 DECEMBER
Ladies Night
"T.C.A. Passenger Service"
Miss Jean Pelletier
and Films

NEWS

Ottawa—Reported by Dr. A. Jaworski

September Meeting

The first meeting of the 1955-56 season of the Ottawa Branch was held at the National Research Council on Tuesday, September 6, 1955. Mr. Orr, Chairman of the Ottawa Branch, presided. The meeting was called to order at 8.30 p.m. and was well attended by over 150 members and guests.

The Chairman opened the meeting with a welcome to the large attendance of members and guests, and asked Mr. M. S. Kuhring to introduce the guest speaker Dr. D. G. Samaras, Sc.D., F.R.Ae.S., Consultant U.S.A.F., Professor Nuclear Propulsion, O.S.U. Mr. Kuhring underlined Dr. Samaras' distinguished career and his work with the National Research Council during the war and in the post-war period.

As Dr. Samaras' paper "Nuclear Propulsion, Aviation's Future" will be reproduced in the Journal in full, no attempt will be made to summarize it here. However, it should be pointed out that the speaker was facing unusual difficulties in addition to the technical novelty of the subject. The difficulties were imposed by the obvious security restrictions and by the request that the lecture should not provide insurmountable difficulties to the general public by introducing higher mathematics which is a "specialité de la maison" of the speaker.

A very lively discussion followed the lecture and the speaker was confident of a rapid progress of nuclear propulsion. He pointed out that the apparent engineering difficulties such as limitation of the materials and the unknown aspects of the psychological limitation that may be involved in interplanetary travelling, one day may be solved, since the technical achievement of to-day has definitely exceeded the most optimistic hopes of the engineers in the last century.

The meeting was closed by the Chairman at approximately 10.30 p.m.

Vancouver—Reported by R. J. McWilliams

September Meeting

The first meeting of the Vancouver Branch went off very well. Forty-five members and guests were present and the meeting was held in the Aero Club of British Columbia.

The first half hour was spent discussing certain business matters. The approval of the Minutes of the May Meeting ratified the previous discussions concerning Branch Regulations.

Two films were then shown. The first, lasting forty-five minutes, was the International Harvester film "Man with 1000 Hands". This is a superb filming of the Kemano and Kitimat projects, of which any one of the five major sections is a tremendous feat in itself. This film was very impressive and is recommended to other Branches.

The second film, produced by the U.S.A.F. was entitled "Crew Safety in Pressure Cabin Flight", quite a good film showing recent developments in flying suit and oxygen equipment for high altitude pressurized flight. Highlights of the film were two sequences depicting the effects of explosive decompression.

The meeting was adjourned at 10.30 p.m.

Montreal—Reported by
E. C. V. Norsworthy

September Meeting

Approximately 125 members and guests of the Canadian Aeronautical Institute, Montreal Branch, and Society of Automotive Engineers, Montreal Section, attended a most interesting lecture on the Technical Aspects of Space Flight which was given by Mr. Darrel C. Romick of the Goodyear Aircraft Corporation at the regular September Meeting of the Montreal Branch. Mr. Romick covered the subject under three main headings: (a) Physiological Factors affecting space flight, (b) An Outline of the Orbital Principles on which space flight must operate, (c) the Vehicles and Techniques, the evolution of which is required to achieve space flight. The main physiological problems which were expected were those involving collision with meteors, the possible damaging effect of cosmic rays, the problems incident to the lack of atmosphere, and the high accelerations which would be expected in the operation of such vehicles. Mr. Romick felt that the possibility of collision with meteors could be considered under two headings, i.e. meteors of sufficient mass to withstand destruction of the earth's atmosphere, and meteors of a smaller size which

would normally burn out before reaching the earth. He felt that the first category presented no problem since expected incidence of collision was no greater than that encountered on the surface of the earth. He further suggested that while the effects of collision with smaller meteors would be destructive to the skin of a space vehicle, damage might be offset by incorporating an outer skin which would absorb any damage due to collision with smaller meteors. Mr. Romick felt that the accelerations encountered would not be of an order greater than 8g since the vehicle itself would be limited to accelerations of this order by structural considerations. Cosmic radiation was not felt to be the problem originally forecast, due to better understanding of the nature of these rays and more information becoming available on the degree of exposure which the human body could withstand, as a result of the investigations in the Atomic Energy Program. Problems due to the absence of atmosphere could be surmounted by a vehicle incorporating a self-contained and airtight cabin, the vehicle transporting its own supply of air and being airtight to prevent high altitude affecting the occupants.

Mr. Romick then examined the orbital considerations governing space flight, establishing that a velocity of approximately six miles per second was necessary to maintain an elliptical orbit varying from 50 to 500 miles from the earth's surface. Having established such an orbit, only a relatively small increase of velocity would be required to increase the diameter of the orbit to any degree necessary. Mr. Romick mentioned that the best single stage rockets that could be foreseen at present would not be able to achieve the required velocity of six miles per second which led to the conclusion that space flight for the present at least could only be achieved using a three-stage rocket, the first and second stages of which would return to earth on the consumption of their fuel. He went on to develop the logistics of such an operation and to discuss the preliminary design studies that had been made covering such a vehicle.

Examining propulsion techniques, Mr. Romick considered that the limitations of a chemical rocket would confine such vehicles to orbits not exceeding those of the planets, and that for journeys beyond this range, a greater supply of energy was required. He examined the possibility of an ion gun or linear accelerator by which ions of a propellent material would be accelerated electromagnetically, the electric power necessary being obtained from atomic sources. Mr. Romick examined this possibility in some detail, pointing out that the exhaust from such a vehicle would be so destructive that its operation from an artificially positioned space station or uninhabited satellite would be essential.

The Speaker was introduced by Mr. Berg, Chief of the Airworthiness Division of I.C.A.O. and thanked by Mr. Schaefer, Assistant Chief Engineer of Canadair.

In thanking the Speaker, Mr. Schaefer mentioned that while he was undecided as to which space flight he would accompany he would suggest Montreal as a proving ground for future space ship crews since the current traffic problems made collisions with only meteors a pleasant prospect, and that boiling of the blood was frequently encountered in the city's frequent traffic jams.

MEMBERS

NEWS

Dr. J. J. Green, F.C.A.I., Past President, delivered the British Commonwealth and Empire Lecture to the Royal Aeronautical Society in London on the 6th October. In 1954 this Lecture was delivered by His Royal Highness the Duke of Edinburgh, now Patron of the Canadian Aeronautical Institute.

C. G. Best, A.F.C.A.I., of Orenda Engines Ltd. addressed the Birmingham Branch of the R.Ae.S. on the 23rd September; his subject was "Some Applications of a Digital Computer to Gas Turbine Engineering".

W/C K. R. Greenaway, A.F.C.A.I., has been transferred by the U.S.A.F. from Tampa, Florida, to Castle Air Force Base, California, on the B-52 programme. W/C Greenaway has been on exchange duty with the U.S.A.F. for about a year.

G. G. Desloovere, M.C.A.I., formerly of Canadiar Ltd. has taken an appointment as a development engineer in the Industrial Electronics Division of Crosley, Toronto.

J. Fleming, M.C.A.I., has gone to Holland on a six months course at the International Training Centre for Aerial Survey at Delft.

D. T. Jackson, M.C.A.I., has left the Department of Transport and joined I.C.A.O. He is posted to Damascus as adviser to the Syrian Government on civil aviation affairs.

W. H. D. Hanchet, M.C.A.I., formerly with Canadian Pratt & Whitney Aircraft Company Ltd., has been appointed Contracts & Service Manager of Doman Fleet Helicopters Ltd., Fort Erie.

R. J. McWilliams, M.C.A.I., has been made Supervisor of Planning, Canadian Pacific Air Lines Ltd.

J. A. Park, Technical Member, has left the National Aeronautical Establishment and has taken an appointment with Computing Devices of Canada Ltd.

SUSTAINING MEMBERS

NEWS

Avro Aircraft Ltd. sent Mr. J. Zurakowski, their Chief Development Pilot, to England to demonstrate a CF-100 Mk 4B at the S.B.A.C. Show. The aircraft used was one of those now undergoing evaluation trials by the R.A.F. From all accounts the performance of the CF-100 made a very favourable impression on the discriminating Farnborough audience and did much to enhance the already excellent reputation of Canadian aircraft in Europe.

Orenda Engines Ltd. also exhibited at Farnborough. Their sectioned and "working" display of the Orenda 11 was a major attraction on the Hawker Siddeley Group stand.

P.S.C. Applied Research Ltd. demonstrated the RΘ Computer at the S.B.A.C. Show at Farnborough this year. This device which was invented by W/C J. G. Wright, R.C.A.F. and developed by engineers of P.S.C. Applied Research indicates to the pilot of an aircraft how many miles he is from base or target and what direction he must fly to arrive there; it provides an automotive navigation system without the need for either ground or airborne transmissions.

Work on automatic navigation systems began in various countries as early as 1935. Research went on in two directions, one concentrated on radio aids, and the other on the development of a dead reckoning instrument, capable of giving the navigator an approximate position.

Aids to navigation such as Gee, Loran, Decca, radio range, and search radar are some of the developments of those who attempted to solve the problem by concentrating on radio. Such systems are reliable and time-tested, but suffer from two distinct tactical disadvantages apart from uncertainties of radio propagation. The main disadvantage of most of these systems is the enormous expense of the large ground stations required for radio navigation; the second disadvantage is their dependence on radio transmissions for operation, which in war time, can be of great advantage to the enemy.

Development of automatic navigation equipment resulted in the introduction of the British Air Position Indicator early in World War II. This device

W/C J. G. Wright with W. F. Haehnel and J. L. McKelvie and components of the RΘ Computer.

automatically computed the aircraft's air position from heading and air speed. To obtain the actual geographical position, wind speed and direction had to be applied manually to the air position. The great advantage of the Air Position Indicator was that the pilot had regained his tactical freedom. Towards the end of World War II the instrument known as the Ground Position Indicator was devised. This equipment was such that wind speed and direction could be added mechanically to produce ground position.

All of the automatic dead reckoning systems were basically the same. They all resolved the distance the aircraft had flown in the North-South and East-West components and indicated the aircraft's present position as latitude and longitude. Although the aircraft's present position can be valuable information for the navigator, he usually requires this information to compute the direction to go to reach his destination and the time required to get there. For this reason it is much more valuable to find the means of expressing position as a distance and bearing from a given point.

The unique feature of the RΘ Navigation Computer System is that the aircraft's position is computed and presented in the most useful form to the navigator, viz:—the distance and direction to any destination chosen before or during flight irrespective of starting point. This computation is effected by taking into account the following factors: – air speed, heading, variation, wind speed and direction without radio transmissions. Thus, the RΘ Computer System is an automatic plotter and navigation computer.

Diversion to alternate bases as a result of unfavourable weather or altered tactical requirements can easily be handled by the RΘ Navigation Computer System. This computation is performed by the use of the Vector Add feature. It is necessary only to know the distance and bearing of the new destination from the original. Controls are provided for setting this information after which the computation is automatically carried out with respect to the revised co-ordinates.

The RΘ Navigation Computer System can make use of information supplied where radio or other fixing aids are available and provides a useful memory during periods of flight without them.

A technical paper on the RΘ Computer System, submitted by Mr. W. F. Haehnel and Mr. J. L. McKelvie, project engineers of P.S.C. Applied Research, will be published in a future issue of the Journal.

The Minneapolis-Honeywell Regulator Company, Ltd., has reported the development of two new pieces of equipment namely a sealed switch, shown in Figure 1, and a non-caging vertical gyro, shown in Figure 2.

The switch, designated the 1EN1-6, has two single-pole, double-throw switching units sealed within the can-shaped metal housing. The housing is evacuated and filled with inert gas under pressure to insure constant operating characteristics regardless of atmospheric change.

Six 6-foot 20 gauge MIL-W-5086 leads project at 90-degree angles from the base of the switch, making it possible to make connections in any direction merely by rotating the switch on its axis.

The 1EN1-6 is designed for bracket type or through-hole mounting. The plunger operates through a 5/8 x 24 threaded bushing one inch in length. The unit embodies an ice scraper at the base

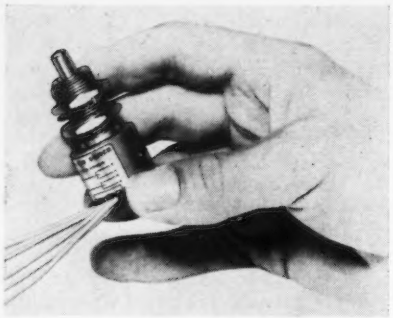


Figure. 1. Sealed switch.

of the actuator to remove mud or ice which might collect on the plunger. The assembly is complete with lockwasher, key washer, and two lock nuts drilled for safety wire permitting approximately 7/8 inch adjustment of the operating point.

Operating force is approximately nine pounds; full over-travel force is approximately 30 pounds and release force is four pounds minimum. Pretravel is .040 inch maximum, overtravel, .250 inch minimum and differential travel is .020 inch maximum. (Contacts open and close within .010 inch maximum simultaneity.)

Electrical rating (at 30 volts, d-c) of the 1EN1-6 is as follows: resistive, 4 amps at sea level and resistive, 4 amps at 100,000 feet; normally-open, 24 amps–inductive, 3 amps at sea level, inductive 2 amps at 100,000 feet. Motor is 4 amps at sea level and 4 amps at 100,000 feet. Inductive load is AN3179-6 Inductor.

The non-caging gyro is designated the GG 33 Vertical Gyro and is a two-axis vertical reference instrument designed to replace earlier non-caging types and also to be used in many autopilot, missile and platform stabilization applications where the caging feature is not required.

Weighing four and one half pounds yet capable of withstanding up to 10 "g's" vibration at 55 cps, the new gyro is designed to give the same performance and accuracy as the company's standard cageable type.

It has pitch freedom of plus or minus

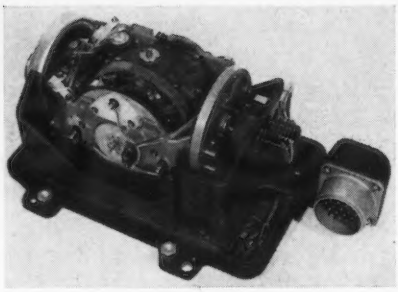


Figure 2. Non-caging gyro.

85 degrees and roll freedom of plus or minus 165 degrees. Resistance of its potentiometer pickoff can be supplied to virtually any specification for greater flexibility of application.

Accuracy is 0.15 degree of true vertical in each axis, drift rate is less than one-half degree per minute and angular momentum is 4.75×10^6 gm-cm^2/sec.

Featuring a 2-6 degree per minute factory-set erection rate, the gyro requires only one minute to reach a usable speed.

MEMBERSHIP OF THE C.A.I.

as at the Meeting of the Executive Committee of the Council on the 28th September 1955.

Technical	**1236**
Associates	**55**
Total	**1291**

The Technical grades comprise the following:

Honorary Fellows	10
Fellows	18
Associate Fellows	171
Members	648
Technical Members	338
Technicians	28
Students	23

SUSTAINING MEMBERS

Of The

CANADIAN AERONAUTICAL INSTITUTE

1955 - 1956

Aeroquip (Canada) Limited
Aircraft Industries of Canada Limited
Alloy Metal Sales Limited
Aviation Electric Limited
Aviquipo of Canada Limited
Avro Aircraft Limited
Babb Company (Canada) Limited
Bristol Aero Engines Limited
Bristol Aero Engines (Western) Limited
Bristol Aeroplane Company of Canada Limited
B. W. Deane & Company
Canadair Limited
Canadian Aviation Electronics Limited
Canadian Car & Foundry Company Limited
Canadian Flight Equipment Limited
Canadian Pacific Air Lines Limited
Canadian Pratt & Whitney Aircraft Company Limited
Canadian Steel Improvement Limited
Cannon Electric Canada Limited
Chatco Steel Products Limited
Computing Devices of Canada Limited
Data Processing Associates Limited
Decca Navigator (Canada) Limited
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D. Napier & Son Limited
Dowty Equipment of Canada Limited
Fairey Aviation Company of Canada Limited
Field Aviation Company Limited
Fleet Manufacturing Limited
Garrett Manufacturing Corporation of Canada Limited
General Controls Co. (Canadian) Ltd.
Godfrey Engineering Company Limited
Goodyear Tire & Rubber Company of Canada Limited
Imperial Oil Limited
Jarry Hydraulics
Lucas-Rotax Limited
MacDonald Bros. Aircraft Limited
Minneapolis-Honeywell Regulator Company Limited
Normalair (Canada) Limited
Northwest Industries Limited
Orenda Engines Limited
Prenco Progress & Engineering Corporation Limited
P.S.C. Applied Research Limited
Railway & Power Engineering Corporation Limited
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Rousseau Controls Limited
Shell Oil Company of Canada Limited
Simmonds Aerocessories of Canada Limited
Spartan Air Services Limited
Thompson Products Limited
Trans-Canada Air Lines
Walter Kidde & Company Limited
York Gears Limited

moving into the picture

With the F.86 and T.33 hydraulic components and landing gear still in quantity production, Jarry Hydraulics moves further into the Canadian aircraft picture with production of CS2-F main landing gear and other hydraulic units for this latest addition to the Royal Canadian Navy now being built by the De Havilland Aircraft of Canada.

Designers and manufacturers of:

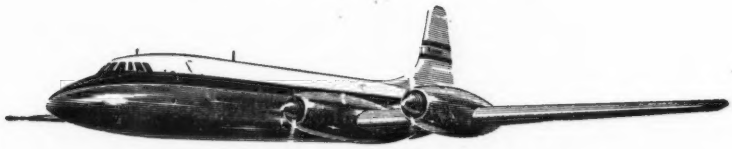
LANDING GEAR
LANDING FLAP ACTUATORS
NOSE WHEEL STEERING MOTORS
CONTROL SURFACE ACTUATORS
DIVE BRAKE ACTUATORS
FUEL PUMPS
BOMB DOOR ACTUATORS
COCKPIT CANOPY ACTUATORS
WING FOLDING JACKS
MISSILE CONTROLS
ACCUMULATORS
COMPENSATORS
TEST RIG ACTUATORS
BALL SCREW ACTUATORS

Hydraulics "know how" has led the entire Canadian aircraft industry to look to Jarry, which now has more hydraulics flying than those of any other manufacturer in Canada. Our highly specialized design staff coupled with a large production department enables us to tackle any hydraulics problem, and to produce precision-made units of consistent top quality.

Jarry Hydraulics

MONTREAL 18, CANADA

TURBOJETS



WHEN THE GAS TURBINE emerged about twelve years ago there was reason to suppose that its apparent simplicity would herald a profusion of different designs and so enable the new power form, with or without propellers, to be tailored to particular aircraft projects. Certainly in principle the engine is simple enough: a single shaft joins a compressor at the front to a turbine at the back. Between them is a continuously burning flame and the turbine collects energy from the heated and expanding gas to drive the compressor, leaving enough residual energy free to escape and propel the vehicle. But in the early days gas turbines often refused to work at all, and despite all encouragement they remained obstinately inert. Later, the gas was persuaded to provide enough power to turn the compressor, and gradually, after refinements, some positive thrust was produced. In due course, one pound of thrust could be generated for each pound of engine weight. This figure has steadily improved and now five pounds of thrust for every pound of engine weight can be achieved: indeed industry expects that later more than one pound of thrust will be obtained for every pound weight of the entire aircraft, so leading to fighters that can push themselves off the ground without forward run. Meanwhile improvements in fuel consumption have been made: until recently one pound of thrust required one and a quarter pounds of kerosene fuel, but now only one pound of fuel is needed. Naturally the penalty for these advances lay in increasing the maze of complexity. The compressor, for instance, instead of being forged from a single solid is now composed of hundreds of precision-formed blades—originally in aluminium, now in steel and titanium. The compressor of the 10,000 lb thrust Bristol Olympus embodies the further principle of duality—each half driven through concentric shafts at different speeds by separate turbines with only a gas connection between them.

Time has shown that the task of evolving a big gas turbine demands fifteen to twenty times the effort that went into the most complicated piston engines. A high proportion of these additional engineering and design man-hours has been spent in unremitting research toward a better understanding of how to handle enormous volumes of air. Instead of using fifteen parts of air to one of fuel as in a piston engine, the gas turbine uses eighty-five parts of air. And naturally the science of guiding air into the engine through the intake with minimum losses is as important as reducing duct losses and turbulence when it is inside the engine. Apart from the aerodynamics, the science of turbine metallurgy has also been in a state of constant change. Early in the career of the gas turbine, aluminium alloys had to be replaced by various chrome and cobalt steels and nickel alloys. Some of these have scarcely had an opportunity to prove themselves before they, in turn, have been overtaken by the properties of titanium, whose immensely important alloys are midway between aluminium and steel in weight and approaching steel in strength.

The result is that new types of turbine engines are now taking some five to seven years to develop, and the gap is widening between the capabilities of 7-10,000 lb engines in production and those with three times the power which are now feasible. Discoveries follow each other in quick succession and there is no hint anywhere that this characteristic pace in turbine technology is slackening. The Engine Division of the Bristol Aeroplane Company is balancing the rapidly expanding frontiers of scientific knowledge with the cycle of production that follows long afterwards in its wake.

THE BRISTOL AEROPLANE COMPANY OF CANADA LIMITED

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CANADIAN AERONAUTICAL INSTITUTE

MEMBERSHIP REQUIREMENTS

Individual membership of the Institute is divided into seven grades requiring qualifications which are defined in Article 7 of the By-laws. These qualifications are summarised in the following table.

GRADE	QUALIFICATIONS	ANNUAL DUES	*SPECIAL ANNUAL DUES
Student	Undergoing a course of study at an approved school of engineering or technology	$1.00	No Dues
Technician	Engaged in technical work in aviation	$3.00	No Dues
Technical Member	Engaged in scientific, engineering, research, manufacture or operation, in aeronautics or related fields, for 4 years or graduated from an approved school of engineering or science	$5.00	$2.00
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Application for membership must be made on the approved form, which can be obtained from the Secretary, and which must be returned to the Secretary on completion. The applicant does not apply for membership in any specific grade, but each application is carefully considered by an Admissions Committee, who submit their recommendations in this regard to the Council. The Council is the deciding body. On admission the applicant is informed of his grading and the appropriate entrance fee and dues.

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The Entrance Fee is $5.00. Members in good standing in the R.Ae.S., I.A.S., I.A.T. or O.A.S., on the 1st of January 1954, who were resident in Canada at that time, are admitted without payment of entrance fee. Students and Technicians are also exempt from entrance fee but must pay a transfer fee, which is in effect a deferred entrance fee, when they transfer later on to one of the senior grades.

*SPECIAL ANNUAL DUES

Members of the R.Ae.S., I.A.S. and E.I.C., who are normally resident in Canada, enjoy a reduced rate of annual dues by virtue of the financial assistance which these bodies render to the Institute. This reduced rate is shown in the right-hand column of the above table.

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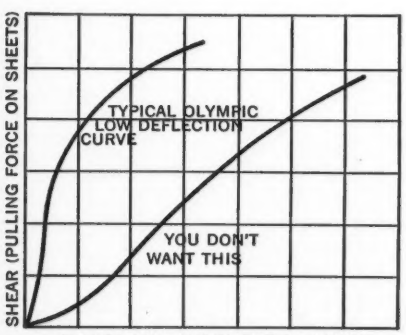

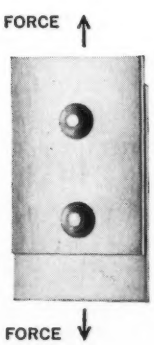

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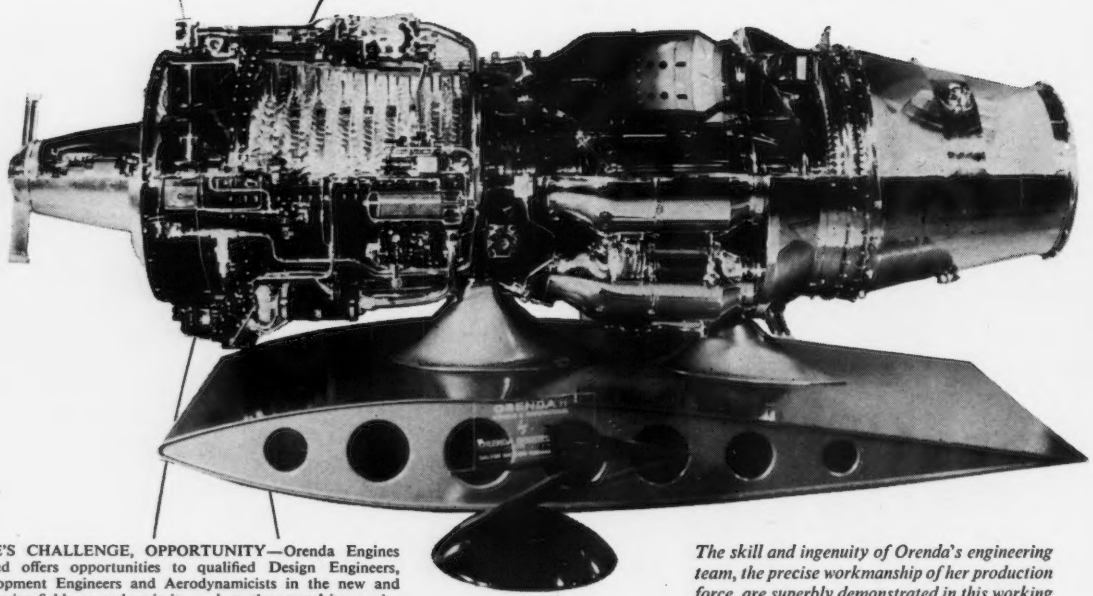

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